

RESEARCH ON DEMINING TECHNOLOGIES

Joint Workshop

PROCEEDINGS

12-14 July 2000 - JRC-Ispra, Italy
Room 3, bldg. 36



EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

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Jointly organised by

The European Commission's Joint Research Centre and
The US Army Electronics Technology and Devices Lab.

Co-sponsored by the European Research Office and the
European Commission DG Information Society through
the ARIS Network of Excellence contract

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EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

2000

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EDITORIAL

Success in overcoming the global tragedy of landmines will only be achieved if the international political and resource commitment is sustained and focused more effectively, international co-ordination is improved, reliable national capabilities are established in all of the most seriously mine-afflicted countries, and safer and faster demining equipment and techniques are introduced.

However, it is also evident that new tools do need the support of the community of researchers. In complement to the development of various technologies for close-in mine detection and mine destruction, programmes exist to support research in various aspects of demining technologies, e.g. development of new sensors, fusion of multi-sensor data sets, development of algorithms for improved detection and identification of landmines, etc. Relevant research programmes are supported in the USA, Canada, EU members states, Israel, South Africa and Japan. In order to provide an inventory of the state of the art and to foster future collaboration this expert workshop was organised with the aim to:

- to assess the state of research in demining technologies,
- to develop recommendations for future research activities,
- to develop means for future international collaboration in this context.

The workshop was restricted to researchers from national research establishments and Universities.

Key topics were:

- new development in sensors,
- sensor fusion,
- signal processing for improved detection and identification of landmines,
- the role of the operator in the detection process,
- establishment of standard data bases,
- identification of topics for future research,
- defining means for future international collaboration.

As chairman of the organising committee I would like to thank the co-sponsors of the workshop:

- the European Commission's Joint Research Centre,
- the US Army Electronics Technology and Devices Lab, and
- the European Research Office

I would like to extend my appreciation for the excellent work to my colleagues of the Organising Committee:

Dr. J.F. Harvey, U.S. Army Electronics Technology and Devices Lab, USA

Dr. D. Weaver, Unexploded Ordnance Center of Excellence, USA

Dr. R. Suart, Director, Canada Centre for Mine Action Technologies, Canada

S.G. Sampath, ERO, USA,

Prof. M. Acheroy, RMA, B.

Last, but not least, I would like to thank all speakers and participants for their excellent contribution to this workshop.

The final discussions and recommendations, included to these proceedings, will be translated by the organisers of the workshop into concrete actions. Even if the workshop focused only on the research community, and may be seen as in isolation from the deminer community, the outcome will allow to improve even existing tools, such as metal detectors, significantly.

Dr. Alois J. Sieber

*Chairman of the Organising Committee
and Editor of the Proceedings*

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CONFERENCE COMMITTEE

A.J. Sieber	EC, JRC, SAI/TDP, Italy
J.F. Harvey	U.S. Army Electronics Technology and Devices Lab, USA
D. Weaver	Unexploded Ordnance Center of Excellence, USA
R. Suart	Director, Canada Centre for Mine Action Technologies, Canada
S.G. Sampath	ERO, USA
M. Acheroy	RMA, Belgium

PROGRAMME

WEDNESDAY 12 JULY, 2000

- 08:00 - **Registration**
09:30 During the registration coffee will be served
9:30 **Welcome**

PROGRAMME OVERVIEWS

Chair: Alois J. Sieber

- 09:40 Overview of US Army Research Office Managed Programs in the Basic Science of Landmine Detection
James Harvey; US ARO
- 10:00 Overview of the US DoD Joint UXO Co-ordination Office Activities
Richard Weaver; JOUXO
- 10:15 Overview on the detection programme of the CCMAT
Bob Stuart; CCMAT, Canada
- 10:30 Projects support by the EC
Wolfgang Boch; EC, DG INFSO
- 10:45 **Coffee Break**

PROGRAMME OVERVIEWS - CONTINUATION

Chair: James Harvey

- 11:15 The role of the EC's JRC
Alois J. Sieber; EC, JRC
- 11:30 The HUDEM project
Marc Acheroy; RMA, B
- 11:45 The UK RTD programm
David Parkes; DERA, UK
- 12:00 The German RTD programme
Manfred Otl Merk; BMV, Germany
- 12:15 The TNO Mine Detection Approach
Piet Schwering; TNO, The Netherlands
- 12:30 **Lunch**

ADVANCED SENSOR SYSTEMS

Chair: Marc Acheroy

- 14:00 Polarimetric hyperspectral imaging
Charles Di Marzio; Northeastern University
- 14:15 Stimulated thermal detection
Charles Di Marzio; Northeastern University
- 14:30 The potential of polarimetric TIR and its state of development
Adam Lewis; DERA, UK and EC, JRC
- 14:45 Recent advances in the detection and identification of landmines by mw radiometry
Markus Peichl; DLR, Germany
- 15:00 Airborne UWB SAR
Larry Carin; Duke University

- 15:15 Design of an impulse UWB GPR system and associated signal processing
Bart Scheers; RMA, Belgium
- 15:30 Interpretation of Signals from Arrays of Electromagnetic Induction Detectors
Yoga Das; CCMAT, Canada
- 15:45 **Poster discussions** with tee, coffee, refreshments

ADVANCED SENSOR SYSTEMS - CONTINUATION

Chair: Marc Acheroy

- 16:30 Modeling of EM and Acoustic Signatures
Larry Carin; Duke University
- 16:45 EMI Detection
Lloyd Riggs; Auburn University
- 17:00 Signal processing tools (imaging and signature modes) for standard metal detectors
Pascal Druyts; RMA, Belgium
- 17:15 Laser induced and detected acoustic detection
Charles Di Marzio, Northeastern University
- 17:30 Use of robotically controlled system for the enhancement of mine detection
Robert Chesney; CCMAT, Canada
- 17:45 **Poster discussion**
- 19:00 **End** of first day - Transport to restaurant
- 19:30 **Dinner** on invitation by the JRC
- 22:00 Transportation to the hotels

THURSDAY 13 JULY, 2000

DETECTION OF THE EXPLOSIVE

Chair: Robert Stuart

- 9:00 State of the art in NQR mine detection - an overview
Neil Peirson; King's College London, UK
- 9:15 Detection of TNT through measurements in soil and air
Michael Krausa; Fraunhofer-Gesellschaft, D

SENSOR FUSION

Chair: Leslie Collins

- 09:30 Characterization and fusion of mine detection sensors in terms of belief functions
Nada Milisavljevic; RMA, Belgium
- 09:45 Sensor Fusion and Thermal Modeling
Brian Baertlein; Ohio State University
- 10:00 EMI, GPR, and MAG Signal Processing and Fusion
Leslie Collins; Duke University
- 10:15 **Poster discussions** with tee, coffee, refreshments
- 11:00 Sensor Fusion of GPR, MD and TIR
Piet Schwering; TNO, The Netherlands
- 11:15 Soft Computing Techniques for GPR detection and sensor fusion
Paul Gader; University of Missouri-Columbia

SIGNATURES

Chair: Giuseppe Nesti

- 11:30 Need for standardized signature data bases and an overview to existing ones
Joaquim Fortuny; EC, JRC

11:45 Joint Multi-sensor Mine Signature Measurement Campaign
Patrick Verlinde; RMA, B, G. Nesti, EC, JRC

ROLE OF THE OPERATOR

Chair: *James Staszewski*

12:00 Human cognition in EMI detection
Leslie Collins; Duke University

12:15 Expert Analysis and Training
James Staszewski; Carnegie Mellon University

12:30 Virtual Minefield
Jeff McMahon; Carnegie Mellon University

12:45 **Lunch**

SUPPLEMENTARY PRESENTATIONS

Chair: *Antonio Urriola Candanedo*

14:00 Mine Detection Test facilities at TNO
Henk Lensen; TNO, The Netherlands

14:15 Yome Proving Grounds UXO Problem in Diverse Environment
Herbert L. Vander Zyl, Soheir Ibrahim; US Army, Arizona

14:30 Panama's International Congress
Gregorio Urriola Candanedo; UTP, Panama

14:45 Waterjet Technology
Robert Mitchell; University of Missouri-Rolla

15:00 Chemical Vapor Detection and Fuze RF Emissions
Robert Mitchell; University of Missouri-Rolla

15:15 **Poster Discussion** with tee, coffee, refreshments

18:00 **End of second day** - Transportation to the hotels

FRIDAY 14 JULY, 2000

09:00 **Round table discussion** on identification of topics for future research, defining means for future international collaboration.

Co-chairs: *James Harvey, Alois J. Sieber*

12:30 **Lunch**

14:00 **Open session – Discussions**

17:00 **End of the workshop** - Transportation to the airport

WORKSHOP COMMENTS

Compiled Friday, 14 July 2000
EC Joint Research Centre, Ispra, Italy

Prepared by

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These comments summarize discussions that occurred on Friday, 14 July 2000 at the Joint EC-US workshop on "Research in Demining Technologies", held at the JRC, Ispra, Italy. Several specific topics were addressed. A list of general recommendations appears at the end of this document.

GENERAL COMMENTS

- (1) The workshop participants generally agreed that the demining/UXO detection community needs a series of workshops of this kind. Several benefits were noted:
 - a. The workshop provides a convenient means of reviewing current research throughout the international community.
 - b. The information exchange was very beneficial.
 - c. It was valuable to have a workshop with a multi-disciplinary view of the demining/UXO detection problem, rather than a one-sensor or one-technology focus. Interdisciplinary interaction produced unexpected benefits.
- (2) Future meetings could have a regional focus to address problems in specific countries, although workshops need not be held at cleanup sites.
- (3) The workshop should avoid duplicating other venues (for example, SPIE Aerosense 2000 or the UXO Forum)
- (4) Narrowly focused workshops (for example, workshops organized by sensor type) might offer benefits to some researchers. The drawback of such focused workshops is that the resulting groups will be small, and most of the people working on specific topics already know each other. In general, cross-fertilization would suffer.
- (5) There is a need for a special group dealing with chemical sensors. That need is not currently fulfilled by any existing forum.

TOPIC 1: Definition of an organizational structure to continue the spirit of the workshop

- (1) A permanent steering committee should be organized to select topics and locations for future workshops.
- (2) Local organizing committees should be appointed to handle arrangements for future meetings.
- (3) The JRC should play a key role in the steering committee, since they are the principal EC demining research group. The US Army NVESD and Canadian CCMAT expressed interest in steering committee membership.
- (4) Steering committee representatives should be sought from any region that intends to develop a permanent demining capability, possibly including Asia, Australia, and the Indian subcontinent.
- (5) The EC wants to focus its near-term efforts on southeastern (SE) Europe, but this does not preclude support to other areas.
- (6) The question of a Panamanian representative on the steering committee was discussed but not resolved. Some comments on that topic and on the possibility of holding a future conference in Panama include the following:

- a. Panama is seeking to develop a center of expertise in demining and UXO remediation. Holding a workshop in Panama would provide an educational opportunity for them. (Similarly, it is attractive to hold a workshop in SE Europe.)
- b. Panama is a tropical environment, offering some unique sensing challenges.
- c. Panama is considering a data collection. The workshop participants comprise a large body of experts with experience in performing such collections. Holding a workshop in Panama would provide an opportunity for workshop participants to offer advice.
- d. The targets in Panama are mostly UXO. Few if any mines are expected.

TOPIC 3: Collaboration on data collections and data exchange

- (1) A lack of standards is hindering progress in algorithm development and collaboration. Standards are needed in the areas of data formats and in defining mine surrogates. URSI is currently responsible for some standard development and may be an appropriate forum for this topic.
- (2) There is a need for standard data sets to be used in testing algorithms. The need is particularly acute for multi-sensor fusion data sets.
- (3) A means of communicating the results of data collections is needed to encourage collaboration, avoid repeating mistakes and reduce duplication of effort.
- (4) JRC is planning a major collection in the near future and requests helpful suggestions from experienced parties. Inputs are requested during the month of August. JRC will organize an electronic forum for the discussion of data collection lessons learned, formats for convenient data exchange, test methods, etc. Anyone interested in participating should contact Major Patrick at patrick.verlinde@tele.rma.ac.be.
- (5) In addition to the data collection issues, there also exist technical questions related to data processing and performance calculations. For example, how should false alarm rate be calculated when several false alarms occur in a small region of space?
- (6) There is a tendency to collect data with no clear goal in mind. We need to identify clear objectives for data collections, and to structure the collections to achieve those objectives.
- (7) There is a need to accurately and quantitatively characterize the soil (that is, not just as "sandy", "clay", "loam", etc.), the targets (mines or mine surrogates), and the environment. Some soil descriptors of interest are electromagnetic properties, thermal properties, and hydraulic properties.
- (8) There is a need to perform well focused data collections with specific objectives. These collections should be organized by the steering committee.
- (9) There exists a great deal of military experience in organizing data collections and disseminating data. NATO and member-nation militaries should be contacted.
- (10) Standardized data collection is a primary function of the International Test and Evaluation Program (ITEP), and their inputs and collaboration should be sought.
- (11) Trials performed during demining tests may have operational aspects. If so, this community should recognize that other groups (e.g., military groups or NGOs) with operational experience should be involved.

TOPIC 4: Making developed computer codes available

- (1) In general, computer models developed during research studies (for example, for Ph.D. work) need additional documentation to be useful to others.
- (2) During a spurt of activity in the US, the MURI programs have produced several modeling codes that may be useful in future demining research. This work may be lost after the MURI ends (September 2001) unless additional work is done and resources are allocated for documentation.
- (3) The limitations of modeling codes are often not known to anyone but the developer. A sophisticated technical background is often required to operate and interpret the models.
- (4) Just documenting a modeling code is not enough. Resources need to be available to provide ongoing support (including telephone or e-mail consultation, bug fixes, and distribution of software and reports).
- (5) Experience with modeling codes in other applications suggests that a dedicated staff may be required to provide support. Support functions are just too cumbersome for cutting-edge researchers.

- (6) It is a large burden for any one country to commit the resources required to support these modeling codes. Joint support is a possibility.
- (7) Further consideration of these issues by the steering committee is called for.

TOPIC 5: Training scientists from developing countries afflicted by land mines

- (1) In general, a means of exchanging scientists and students is desirable.
- (2) Future workshops could be used as a vehicle for promoting exchanges between research organizations.
- (3) Technical staff from afflicted countries should be invited to conferences.
- (4) SE Europe has a large population of educated, motivated workers that could be brought to bear on their regional demining problem.

TOPIC 6: Publishing the results of the workshop

- (1) Consideration is being given to publishing technical papers based on the oral workshop presentations. (This is in addition to the request for copies of the transparencies.)
- (2) Several publication venues are being considered, including a proceedings, or a special issue of an existing journal. The Demining Technology Information Forum is another possible venue, which should be available soon.
- (3) Any request for technical papers is a significant change in the original spirit of the workshop. (Originally, summary presentations were suggested.) Not all presenters may be able to prepare a paper, since the request for a technical paper is coming as an afterthought.
- (4) A permanent record of the workshop (in some form) should be published to capture the results presented here.
- (5) Less formal papers are preferable because they are easier to prepare, but the usefulness of the result rather than ease of preparation should be the primary concern in documenting the workshop.
- (6) Resolution of this matter was deferred to the steering committee.
- (7) The decision to publish results from future workshops should be made by the steering committee or by a local workshop organizing committee.

RECOMMENDATIONS OF THIS WORKSHOP

The following recommendations were generally agreed to by the workshop participants:

- (1) The comments made during this discussion (as documented here.)
- (2) Existing research programs should be continued
- (3) New research programs should be initiated in the following areas
 - a. Advanced sensor systems
 - b. Detection of explosives
 - c. Sensor fusion
 - d. Signatures
 - e. The role of the operator

PROGRAMME OVERVIEWS

OVERVIEW OF THE US ARMY RESEARCH OFFICE MANAGED PROGRAMS IN THE BASIC SCIENCE OF LANDMINE DETECTION

James Harvey
US Army Research Office


ARO Landmine Detection Programs
<p>Problem: Too many landmines, too many types and shapes Too much clutter with similar size and signature</p> <p>6.1 Approach: Understand the basic science of how buried objects generate sensor signatures and how the signatures can be processed. Exploit this understanding to improve the detection of landmines and their discrimination from clutter. The more we understand of the subsurface effects, the better we can detect.</p>

ARO Landmine Detection Programs
<p>6.1 Programs: Demining MURI: Multidisciplinary University Research Initiative Directed and funded by DDRE, managed by ARO \$3.2M /yr for 5 yrs Terminates end of FY01 25% Redirection at 3 year point</p> <p>ARO Landmine Detection (LMD) Program ARO core funded and managed \$0.75M /yr for 2.5yrs Terminated end of FY00</p> <p>Core ARO projects FY00 \$113K, FY01 \$72K</p> <p>18 Universities, industry transition partners, cross disciplinary</p>

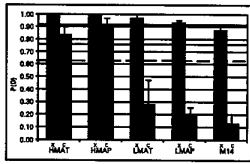
Demining MURI Teams	
Option	
Duke Univ. - <i>Lead</i>	Northrup Grumman
Cal. Tech	EG&G
Georgia Tech.	Hughes
Ohio State Univ.	Geophex
Stanford Univ	
Option	
Northeastern Univ. - <i>Lead</i>	MIT Lincoln Lab
Boston Univ.	GEO-Centers
Univ. of Oklahoma	Aerodyne
Option	
Univ. of Missouri - Rolla - <i>Lead</i>	Texas Instruments
Univ. of Missouri - Columbia	Caterpillar
Carnegie-Mellon	Allied Signal
Univ. of Kansas	

ARO LMD PROGRAM
<p>Human Cognition (Dr. Cookmeyer ARO) Role of Operator in Handheld Detection Optimum CMU Prof. Staszewski Acoustic Signal for Operator Duke Univ Prof. Collins</p> <p>Acoustic Detection (Nonlinear Effects) (Dr. Reeber ARO) Stevens Inst Tech Prof. Donskoy</p> <p>X-ray Lateral Migration Radiography Imaging (Dr. Lavery ARO) Univ Fla Prof. Dugan</p> <p>Tomography from Multiple Scattered Waves (Dr. Lavery ARO) UNCCCharlotte Prof. Klibanov</p>

ARO LMD PROGRAM
<p>EM Effects: Near field, Evanescent Field, Quiet UWB Pulse Antenna (Dr. Harvey ARO) Georgia Tech. Prof. Glenn Smith</p> <p>Physical Environment - Soil Model - Effects on Signatures (Dr. Harmon ARO) New Mex. Inst. Mining & Tech Prof. Hendrickx</p>

HUMAN COGNITIVE PROCESSING FOR LANDMINE DETECTION	
<p><u>KEY CONCEPT</u></p> <p>Optimize the cognitive systems of the operator together with the signal processing system of the detector as equal processing partners.</p> <p>Beyond man-machine interface. Beyond human factors.</p>	
<p><u>GOALS</u></p> <p>Quantify role of operator in field tests of detectors</p> <p>Separate operator - machine performance</p> <p>Optimize division of signal processing tasks human - machine</p> <p>Optimize information flow human - machine</p>	<p><u>MOTIVATING OBSERVATIONS</u></p> <p>Operators do better than machines alone</p> <p>Experts do better than the troops</p> <p>Operators find "undetectable" mines</p>

Expert Performance Analysis Training Enhancements Carnegie Mellon Univ and USAEC&S



Enhancement in Performance of Induction Detector Operators Due to Feedback Training Blue is the performance of control group with standard AIT training Red is the performance of experimental group with new training (15 hours)

TRAINING APPROACH

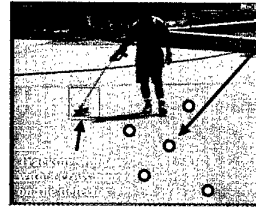
Focus on probability of detection
Maximize hands on practice with feedback
Hierarchical Training: start simple, advance to more complex tasks

UNCONVENTIONAL EXPERT TECHNIQUES

Calibration and sensitivity checks
Sweep techniques
Develop spatial footprint
Airborne localization
Recognize and interpret signal patterns

Tracking Software

3D Tracking and Feedback System



Coverage map

Mine marker

Sweep rate graph

Virtual Mine Lane

Measured Parameters:
- Sweep rate
- Height from the surface
- Coverage

Detector Simulator

Database of locations and models of the mines

Illustration of the virtual mine lane in operation

Role of Operator Human Cognition in Landmine Detection

Approached expert performance with soldier operators with modest training — analysis of expert performance and training feedback

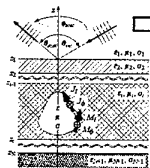
Virtual minefield — training feedback, realistic software driven, adaptive soil and environmental conditions

Begun analysis of operator processing of audio signals from detectors

Major contribution to HSTAMIDS Red Team

Opportunity — Focus on the operator as an equal signal processing partner to the machine

Physical Model Coupled with Signal Processing



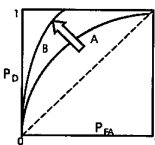
Maxwell's Equations for Mines and Clutter in Realistic Soil

Target and Clutter Signatures Statistical Variations

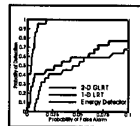
$$AQ = \frac{\int p(r|T, H_1) p(T) dT}{\int p(r|C_{min}, H_0) + 2p(r|C_{min}, H_1) + \int p(r|T, H_1) prob(T) dT}$$

Statistical Based Signal Processing

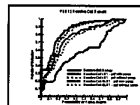
Driving the Detector Curve to the Upper Left
Curve A: Current detectors
Curve B: Current detectors with advanced processing



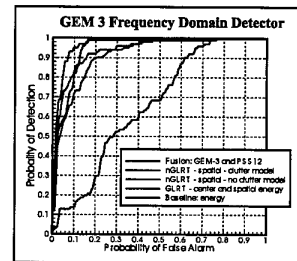
Metal Detector Improvements



Frequency Domain Detector
DARPA Clutter Data
Metal Mines only
Mainly AT

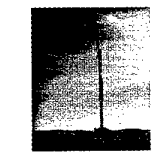


PSS-12 Pulsed Detector

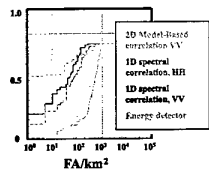


JUXOCO Test Grid
Clutter selected to confuse
Very "stressing" layout
Mixed mine types, many low metal
Blind trial

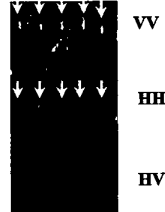
STANDOFF DETECTION



ARL Ultra-Wideband (UWB) GPR BoomSAR
70% Prob of Detection, 1 False Alarm / Sq. KM
Feasibility of Minefield Detection with UWB SAR
from Airborne or Forward Looking Vehicle

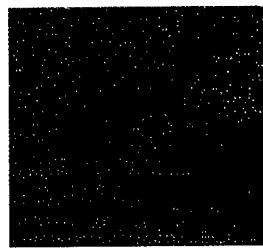


VAMPIRE EFFECT



ARL BOOM-SAR DETECTION

1.7 KM



Before Processing (Energy Detector)

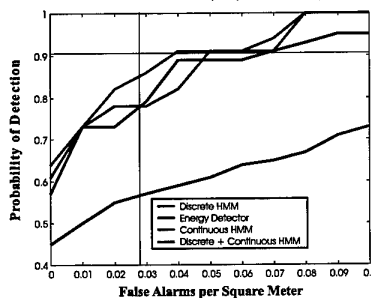


After Processing

Fuzzy Logic Signal Processing

Applied to Vehicle Mounted Ground Penetrating Radar (GPR) Data
Fusion of Continuous and Discrete Hidden Markov Models

AT Mines at Ft. AP Hill, VA, and Socorro, NM



Modeling and Signal Processing

- Demonstration of robust factors of >10 FAR reduction for EMI and GPR, MAG
- EMI Void Detection --- Nonmetallic Mines with Metal Detector
- Demonstration of Bayesian and Soft Computing Signal Processing (Fuzzy Logic, Hidden Markov Model, Neural Net)
- Beginning to incorporate realistic target models
- Capability to do 3D target/clutter modeling in inhomogeneous soil
 - FDTD
 - FDFD
 - Method of Moments
 - Fast Multipole Method for Layered Media --- DoD HPC
 - Robust Physical Features of target signatures
- Beginning to model detailed inhomogeneous, dynamic soil physics (eg. moisture collection)
- Major contributions to HSTAMIDS, VMMD, GSTAMIDS, SERDP
- Opportunity: The better the physical model of target and clutter the better the signal processing

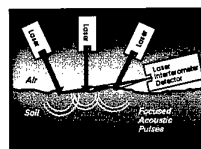
NOVEL EM APPROACHES

- Evanescent Mode Detection (can beat the diffraction limit)
- Theoretical analysis of idealized problem - specially good for lossy ground
- Symmetry Concepts (can beat the diffraction limit)
- Polarimetric Extinction demonstrated
- GPR Near Field Array - Analysis and signal processing concepts
- New Antenna Concepts for GPR
 - UWB Quiet Antennas - Extensive analysis, prototype
 - Dielectric Rod Antenna - Prototype and analysis
 - UWB Conical Spiral - Near field analysis near ground
 - Parabolic Antenna
- Surface Waves - primarily speculation
- Tomography and inverse scattering
- Tomography - Analytical processing and initial field experiment
- X-ray Lateral Migration Imaging - Lab experiments, 2-4 in burial

DEMINEING MURI

Acoustic Detection

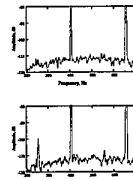
Laser / Acoustic



Radar / Acoustic

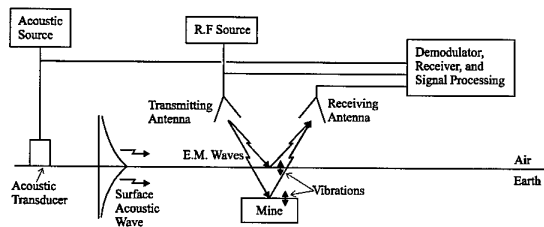


Nonlinear Acoustic



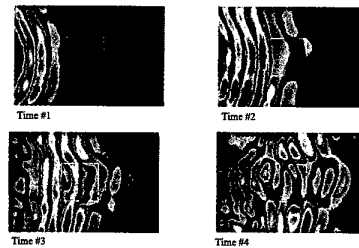
- Complements Radar Detection
- Best propagation in wet soil
- Large sound speed contrast between clutter and mines different from radar dielectric contrast
- Opportunity for novel sensor fusion

Acoustic - Radar Interaction



- Imaging time dependent acoustic wave field using radar
- Radar detects movement of ground particles

Acoustic - Radar Interaction

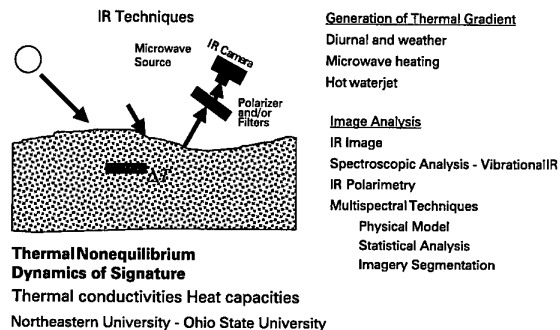


- Mine 2 inches below surface
- Acoustic waves seen above mine
- Waves above mine cut off for low frequency - determines depth

ACOUSTIC / SEISMIC DETECTION

- Demonstration of laser generated acoustic pulses and initial effort at signal processing of target signature (lab)
- Demonstration of laser vibrometer detection and initial efforts at signal processing of signature (field)
- Demonstration of radar/seismic detection (laboratory)
- Demonstration of non-linear frequency conversion of signature
- Beginning modeling of target signatures in poro-elastic media
- Beginning to understand fundamental physics of phenomena
- Very promising area
- Just getting started
- Major NVESD Program Funding and Support

DEMINING MURI



THERMAL SIGNATURE

- Demonstrated Polarimetric Hyperspectral Unique signatures of man-made objects
- Dynamic model of the diurnal cycle
- Demonstrated microwave control of thermal heating cycle
- Initiated Collaboration with ARL and UK - High Power Microwave Stimulation — Thermal Conductivity, heat capacities
- Hot waterjet demonstrates dramatic shape following effect
- Passive Microwave - Theoretical Analysis
 - Oscillation in frequency - signature
 - Wideband system to maximize discrimination
 - Detailed clutter and surface roughness analysis
 - Optimized angles of observation vs frequency and vs clutter and surface statistics

SENSOR FUSION

- Decision level and feature level preliminary results
 - Factor of 2 improvement in FAR (EMI, GPR, IR)
- Bayesian and Soft Computing Techniques
- Mainly data oriented
- Opportunity: Overarching a priori theory

MINEFIELD MODIFICATION

Water (10-20%) demonstrated to significantly improve contrast for radar detection of shallow nonmetallic and low metallic AP mines, even for Ghz frequencies.

Liquid nitrogen demonstrated to significantly improve radar penetration for very high moisture content (30%).

Hot waterjet significantly improves thermal signature.

ELECTRONIC MINES and FUZES

- Demonstration of detection of buried timing chips
- Investigation of coupling to fuze circuits
- Stimulation of non-linear response
- 6.1 Opportunities:
 - Detailed analysis of coupling via wires and into metal casings
 - Detailed analysis of opportunity for nonlinear effects
 - Modulated high frequency probe signals

CHEMICAL DETECTION

- Polymer based olfactory sensor (Dog's nose)
 - Factor of 10 faster response time
 - 5 orders of magnitude increase in sensitivity
- Quadrupole Resonance Detector
 - Modeling and Signal processing to enhance TNT signature to noise
- Combined EMI and QR
- Resonant Electron Capture Detector
 - Excellent lab results

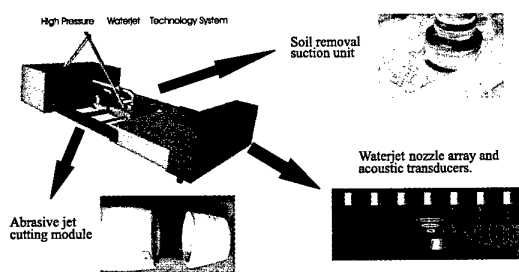
CHEMICAL DETECTION

6.1 Opportunities

- Polymer based olfactory sensor (Dog's nose)
 - Polymer chemistry
 - Complex impedance detection
 - Signal processing
- Quadrupole Resonance Detector
 - Explore Combination QR / EMI detector
- Resonant Electron Capture Detector
 - Field experiments
 - Signal processing

DEMINING MURI

WATERJET MINE CLEARANCE

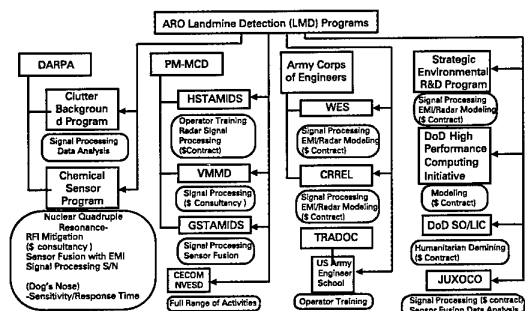


★ Safe one-pass detection and neutralization (efficient, rapid, environmentally sound)

WATERJET MINE CLEARANCE

- Demonstrated target detection and location via acoustic signal from water pulse
- Demonstrated that force produced by waterjet can be controlled below mine fuze threshold
- Demonstrated that waterjet/soil suction can remove soil exposing mine to various probe techniques
- Demonstrated that abrasives/hurryjets can safely cut through detonator to neutralize mine
- Demonstrated distinctive thermal signatures from heated waterjet
- Waterjet holes provide opportunity for probe access from sides or below

WELL CONNECTED TO TRANSITION PROGRAMS



OUTREACH AND COORDINATION

International Collaborations

UK: High Power MW stimulated Thermal Signatures
New Capability for Quadrupole Resonance Technique

Canada: MW Stimulated Thermal Signatures
GPR and EMI Array Data

Belgium: High Resolution EMI Imaging and Processing

Denmark: Thermal Signatures

European Commission (JRC): Thermal Signatures
Signature Data Collection
Radar Signature Facility
Proposed Structure for International
Collaborations and Workshops

OUTREACH AND COORDINATION

SPIE AEROSENSE MEETING Orlando 13-17 April 1998
Conference on Detection and Remediation Technologies for Mines and Minelike Targets
Conference CoChairs Dubey, Broach, Harvey
42 MURI/ARO LMD papers out of 110 on landmine detection

April 1999
April 2000

First short course on statistical physics based signal processing developed and presented by MURI's 1999, 2000

Edit Books: Advances in the Science of Landmine Detection - next year

CONCLUSIONS

Significant Transitions to Development Programs

Focus on Fundamental Science and Basic Understanding - Paid Off
The more we know about the subsurface, the better we can detect and discriminate landmines

Emphasis on Physical Modeling coupled to Statistical Signal Processing - Paid Off

Near and Far Term Potential

To exploit 6.1 opportunities, a sustained 6.1 effort is more important than its magnitude

Real Momentum in this field and Very Significant Transitions

Significant 6.1 left to do, plus unknown ideas out there

Factors of 10 remaining in performance improvement, but only with the science understood

PROMISING AREAS

Realistic Target and Clutter Signatures --- all sensors (EMI, GPR, acoustic, thermal, chemical, etc.)
Signal Processing, especially for Acoustic, Thermal, Chemical, etc. Fusion
Airborne Minefield Detection (hyperspectral thermal, UWB GPR)
Forward looking standoff detection
Fusion Theory
Acoustic Detection
Active EM Detection Active Sensors and Electronics
Chemical Detection (Explosive Specific, includes nuclear techniques)
Imaging --- X-ray and other
Novel Electromagnetic
?????????? This is Basic Research

ADVANCES IN THE SCIENCE OF LANDMINE DETECTION FROM US ARMY BASIC RESEARCH PROGRAMS

James F. Harvey

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Tel: 1-919-5494244, email: harvey@arl.aro.army.mil

In 1996 the US Office of the Secretary of Defense initiated a large multi-university basic research effort directed at understanding the underlying science of landmine detection for Humanitarian Demining, in the Multidisciplinary University Research Initiative (MURI) program. This Humanitarian Demining program consisted of 3 teams of universities, with participating industrial partners, and is program managed by the Army Research Office in the Army Research Lab. It was funded at \$3.2 M/year for 5 years and will be completed by the end of 2001. In 1998 a smaller research program on landmine detection (LMD) was initiated within the Army Research Office, with internal funding. The ARO LMD program was funded at \$750K/year for 2.5 years and will be completed by the end of 2000.

The thesis of this program has been that if we understand the science of the interactions of various probing phenomena with landmines and clutter, we can do a better job of discrimination. The emphasis has been on understanding the phenomena, however several very real and near term transitions have been made to developmental and technology demonstration programs, largely in the field of advanced signal processing techniques and operator training. Progress in sensor fusion has been slower due to a limited amount of coregistered data, however good data sets are becoming available and promising preliminary results have been obtained. At the same time significant advances have been made in fields of landmine detection which have not been extensively exploited previously, such as acoustic detection, soil and atmospheric environmental effects on landmine signatures, innovative EM effects, the understanding and stimulation of thermal signatures, polarimetric hyperspectral signatures, the detection and stimulation of electronic signatures from electronic fuzes in smart mines and booby traps, and the detection of explosive vapor. An interesting variation of a mechanical probe is the waterjet technology, which has the capability of detecting, digging up, cutting, and disarming buried landmines. The waterjet system also may have the potential to enhance a time dependent thermal signature and to enhance a chemical vapor signature. The waterjet technology has graduated from the realm of basic research into consideration for development programs.

One emphasis in these programs has been on the concept that additional target and clutter signature information, beyond the simple magnitude of the signal, can be utilized in advanced signal processing algorithms to significantly enhance the performance of the detector. The spatial distribution of the signal and its temporal or frequency response have been effectively exploited for Electromagnetic Induction (EMI) and ground penetrating radar (GPR) detectors using Bayesian and soft processing techniques such as fuzzy logic and hidden Markov models. The techniques have demonstrated factors of 4 to 12 reduction in false alarm rate compared with an energy (thresholded signal magnitude) detector. The feasibility of ultrawideband (UWB) GPR for airborne or standoff detection of metallic mine fields has been demonstrated and preliminary results are promising that the same system can detect plastic mine fields under favorable (wet) environmental conditions. The same techniques are being applied to feature level sensor fusion algorithms, in addition to decision level fusion schemes. Because of the tremendously large number of parameter variations of the signal due to detector and target orientation, the environmental conditions and statistical variations of the soil and surface, and the large variety of clutter, the determination of the probability distributions necessary for the signal processing and the physical understanding of the signatures requires the physics based modeling of the signatures under realistic soil conditions. A variety of modeling and simulation techniques have been developed to provide realistic three-dimensional capability.

A second emphasis in these programs was on the human cognitive contribution of the operator to the detection process. Here the brain and sensory system of the human operator is treated as an equal signal

processing partner with the sensor processor and the total system is optimized to achieve superior detection performance. Substantial anecdotal evidence exists that the operator of a handheld system can make a major contribution to the overall performance. The initial approach in this program was to analyze the thought processes of expert EMI operators. A model of the experts' performance was created which involved a mental analysis of the spatial signature. Although most engineers have a natural capability to visualize spatial structures, this is not a characteristic of the general population, which supplies most of the operators. A training routine was developed using feedback techniques to teach this spatial analysis. The feedback system was based on an optical 3D tracking approach, with software controlled simulated mine signatures, which could provide instant feedback to the operator and/or his trainer. The feedback system was also very effective in teaching difficult skills in sweep coverage and sweep technique. The training required was a modest 15 hours. This training approach was tested using an experimental group and a control group of soldiers from the US Army Engineer School. The control group received only the standard training given soldiers in their Engineer branch advanced individual training. The results show dramatic improvements in performance in detecting low metal mines and still significant improvements in the detection of metallic mines. The feedback system constitutes a virtual minefield, which can be used to train or refresh operators for specific environmental and soil conditions and specific landmine types using software driven simulated signatures and the optical projection of terrain texture on a neutral surface. This system has the potential for application beyond training situations.

Novel EM approaches are being examined. Near field (and evanescent) detection modes can be used to achieve resolutions well beyond the far field diffraction limit. Symmetry effects can also be used to obtain shape information at resolutions well below a wavelength. For example, the whimsically named "vampire effect" results when the cylindrical symmetry of the landmine won't support a cross-polarization GPR response. The mines are detected by comparing the co-polarization image with the cross-polarization image (How do you find a vampire? You look for the image that isn't there). Tomographic techniques hold the promise of extracting better shape information from signals with a significant clutter scattering. X-ray imaging, while limited in depth to shallowly buried mines, can provide very dramatic shape information for discrimination.

Acoustic and seismic techniques provide fundamental information about buried objects that is complementary to the information from EM sensors. For example, the dielectric constants of plastic mines and dry soil can be very similar, resulting in little radar contrast, while the speed of sound in the materials is very different. Likewise, the speed of sound is very different in landmines than in radar clutter items such as rocks or tree roots. In addition, acoustic propagation improves with soil moisture, contrary to the behavior of radar waves. The ARO managed research programs address issues of acoustic propagation modeling, the creation of acoustic signals in the soil using laser beams, the mapping of the near surface seismic field using GPR, signal processing to exploit the acoustic and seismic signatures, the unique signatures from nonlinear acoustic detection, and some of the issues involved in laser-doppler imaging of the ground vibrations. Acoustic approaches to landmine detection appear to be especially promising, with significant potential value in a fused sensor suite.

The combination of hyperspectral imaging with polarimetric imaging, with each hyperspectral data bin resolved in polarization, appears to have encouraging potential for detecting landmines.

These research programs have produced a highly effective model of the thermal IR signature of buried mines. The model has demonstrated interesting effects, such as the tendency of most clutter signatures to change in time with the opposite phase of the buried mines, which can be used for discrimination. Microwave heating of buried mines and their surroundings has been investigated in order to control the diurnal thermal signature cycle and to exploit temporal effects on these signatures.

The attached vugraph slides describe these issues in more detail and also enumerate several other research areas addressed by these programs.

OVERVIEW OF THE US DOD JOINT UXO CO-ORDINATION OFFICE ACTIVITIES

Richard Weaver
JOUXO

OUTLINE

- Introduction
 - Purpose
 - Background
 - Motivation
- Discussion
 - Test Description
 - Data Collection
 - Signature Issues
- Findings

PURPOSE

- Describe Data Collection Grid, Targets and Clutter
- Discuss Data Collection Procedures
- Present Sample "Signatures"
- Summarize Findings

BACKGROUND

- Mines/UXO come in wide variety of sizes, shapes, materials
 - Metal Case
 - Plastic Case (<1gm metal)
 - No Metal
- Present Best Sensors (Metal PR's, IR) Detect Secondary Features (anomaly)
 - Little Ability to Discriminate Targets from Clutter
 - High False Alarm Rates
 - Simple Thresholding Algorithms
- Data Collection Focussed on System Level Performance (RAR)
 - Little Basic Sensor/Target Signature Data
 - Often Not "Ground Truthed"
 - Performance Varies Widely for Different Environments and Clutter Backgrounds
 - Lack of "Standard" Targets

Difficult to Compare Systems and Measure Progress

MOTIVATION

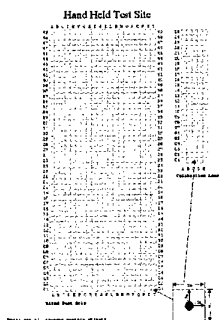
Create a database of mine signals data to advance understanding and support sensor development

- Working to provide:
 - Standard Targets
 - Testing Protocols
 - Scientific Data Collection
 - Signal Processing Algorithms
 - Test Site Development



- Promotes sharing of sensor data/signal processing across DoD, industry, academia, and internationally via UXOCOE Web Site (www.denix.osd.mil/UXOCOE)

TEST SITE LAYOUT



STAKING OFF SITE



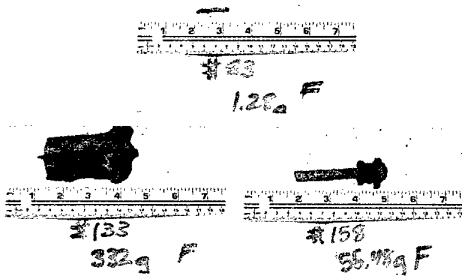
HAND CLEARING AND COLLECTION OF CLUTTER



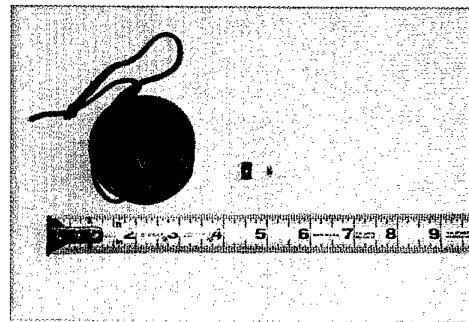
TABLE OF TARGETS AND PROPERTIES

Mine Name	Type	Diam (cm)	Container	Total Metal (gm)
VAL-69	AP	10	Plastic	2800.000
TM-46	AT	30	Metal	2406.000
VS-50	AP	9	Plastic	18.210
TS-50	AP	9	Plastic	4.408
VS-2.2	AT	23	Plastic	3.290
M-19	AT	33	Plastic	0.940
TMA-4	AT	28	Plastic	0.750
M-14	AP	6	Plastic	0.600
PMA-3	AP	10	Plastic	0.350 / 0.840
TM-62P3	AT	32	Plastic	
TYPE 72	AP	8	Plastic	

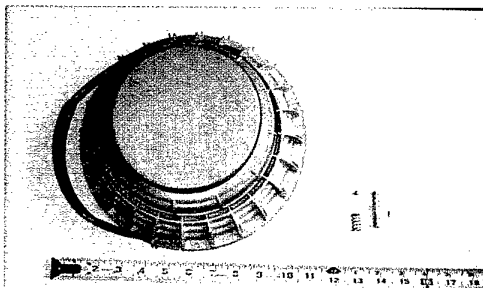
TEST SITE "CLUTTER" SAMPLES



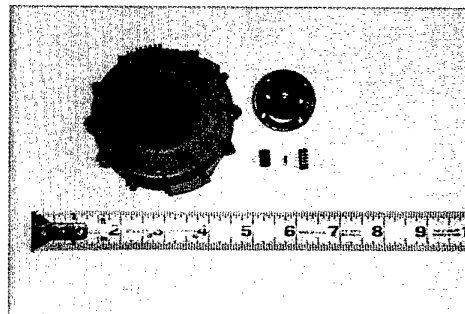
M-14 AP MINE W/ METAL COMPONENTS



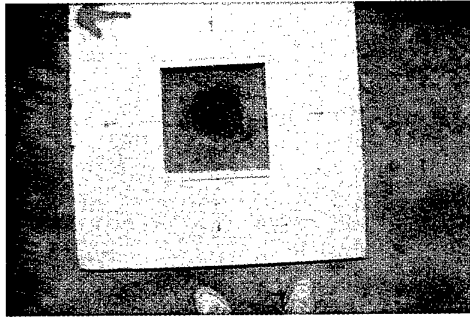
VS 2.2 AT MINE W/METAL COMPONENTS



TEST SITE SAMPLE TARGET VS-50 AP MINE



TARGET/CLUTTER POSITIONING

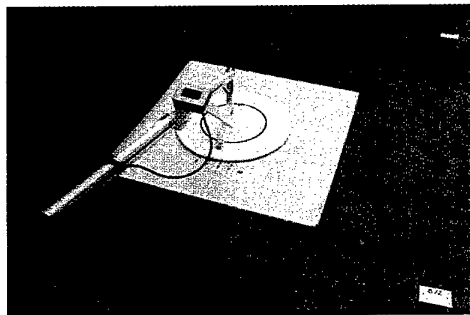


TEST SITE SAMPLE OF "CALIBRATION" LANES

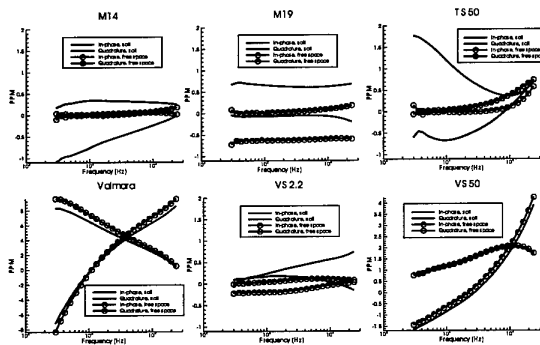
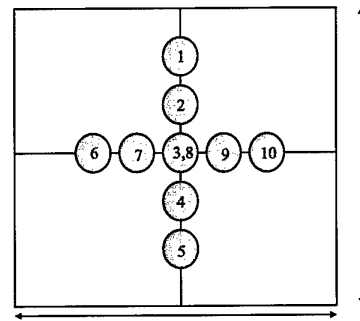
10		B10		D10	
09	A9		C9		
08		B8		D8	
07	A7		C7		
06		B6		D6	
05	A5		C5		
04		B4		D4	
03	A3		C3		
02		B2		D2	
01	A1		C1		
	A	B	C	D	E

A1: Clutter (#091) 44.73g; Ferrous; 1.5"
 A3: Clutter (#095) 07.59g; Non-Fer; 1.0"
 A5: Clutter (#127) 12.92g; Non-Fer; 3.0"
 A7: Clutter (#129) 306.0g; Ferrous; 2.7"
 A9: Clutter (#148) 00.43g; Ferrous; 1.4"
 B2: VS-50 18.21g; Surf-Flush
 B4: VS-50 18.21g; 1"
 B6: VS-50 18.21g; 1.875"
 B8: TS-50 4.408g; Surf-Flush
 B10: TS-50 4.408g; 1"
 C1: Clutter (#315) 01.06g; Ferrous; 1.0"
 C3: Clutter (#147) 00.85g; Ferrous; 1.5"
 C5: Clutter (#146) 00.43g; Ferrous; 1.8"
 C7: Clutter (#319) 00.86g; Ferrous; 1.5"
 C9: Clutter (#337) 03.43g; Non-Fer; 0.8"
 D2: VS-2.2 3.29g; 1.438"
 D4: VS-2.2 3.29g; 3.25"
 D6: M-19 0.94g; 1.75"
 D8: M-19 0.94g; 2.5"
 D10: TMA-4 0.75g; 1.75"

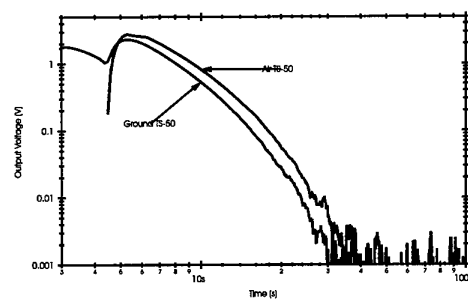
GEM-3 SIGNAL DATA COLLECTION



DATA COLLECTION Grid Square Spatial Sampling

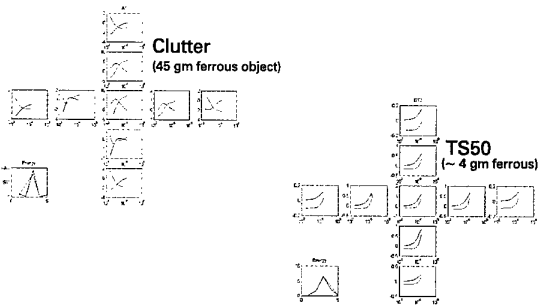


TS-50 AP MINE Air vs Ground Measurements*

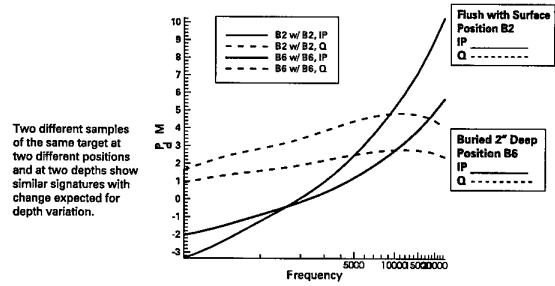


* Carl Nelson JHU TEMID Sensor

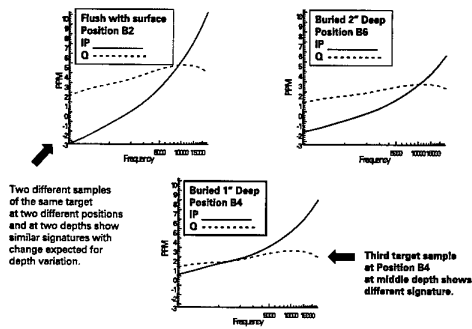
ALGORITHM ACTIVITIES GEM-3 Spatial Signature Examples - Prof. Leslie Collins Duke Univ.



"SIGNATURE" VARIABILITY VS-50 Targets From Calibration Lane (GEM-3 Data)

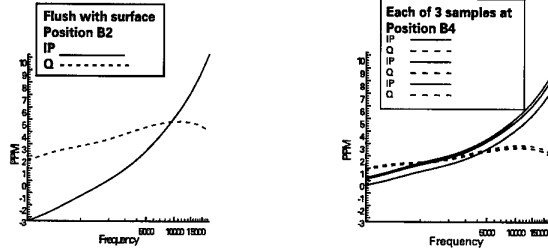


"SIGNATURE" VARIABILITY VS-50 Targets From Calibration Lane (GEM-3 Data)

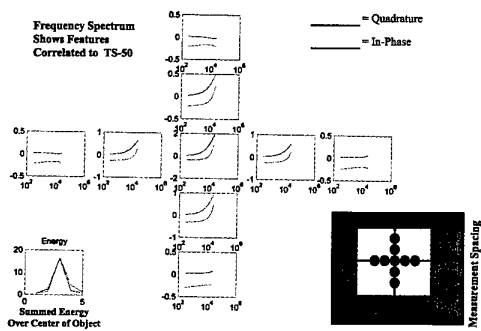


"SIGNATURE" VARIABILITY VS-50 Targets From Calibration Lane (GEM-3 Data)

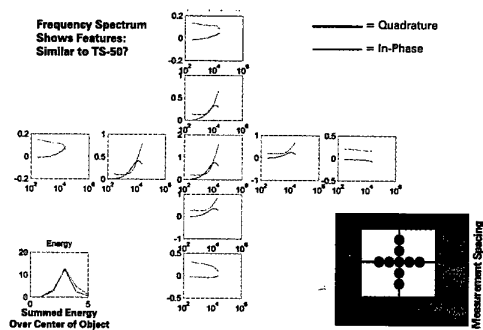
While a target in Position B2 illustrates the expected "signature" (left), three data sets from Position B4 (right) show the same shift in signature for three different target samples (including B2 sample), correlating "signature" shift to Position B4.



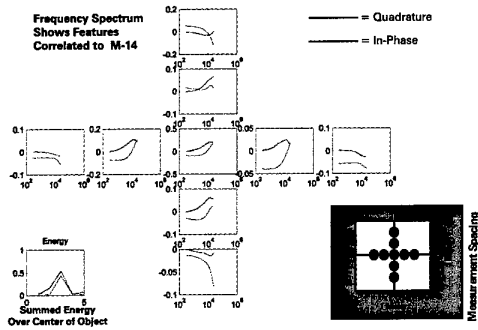
Example of GEM-3 Frequency Spectrum Over a TS-50 Antipersonnel Mine



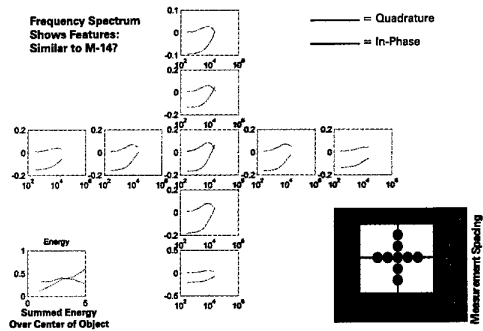
Example of GEM-3 Frequency Spectrum Over Iron Clutter, < 2grams



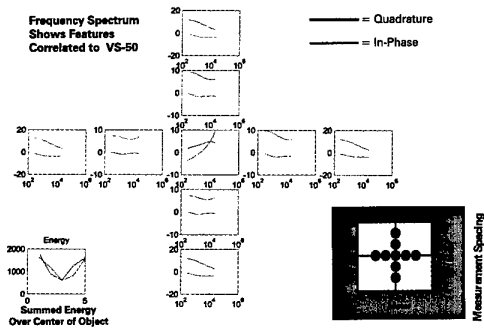
Example of GEM-3 Frequency Spectrum Over a M-14 Antipersonnel Mine



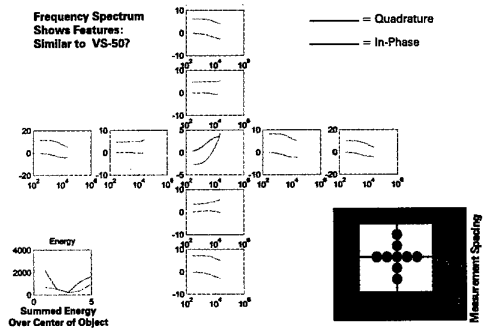
Example of GEM-3 Frequency Spectrum Over a Filled Hole



Example of GEM-3 Frequency Spectrum Over a VS-50 Antipersonnel Mine



Example of GEM-3 Frequency Spectrum Over Iron Clutter, > 20 gm



GENERAL FINDINGS

- Soil Effects Dominate The Mine "Signature" Issue
 - "Low-metal mine "signatures" measured in air differ significantly from "signatures measured in the ground
 - Buried "low-metal" mine "signatures" can be dramatically affected by variations in soil properties OVER A SMALL DISTANCE (± 1 METER)
- Soil / Environmental Effects Create Multiple Mine "Signatures" for the Same Target
 - Detection and discrimination problem must be dealt with in a probabilistic sense not a deterministic one
 - Signal processing techniques must account for statistical nature of signatures
- Advanced Statistical Processing Techniques have shown Vastly Improved Ability to Distinguish Mines from Clutter
- Collecting Multiple Measurements Around a Suspected "Target" (Spatial Data) Improves Discrimination Ability

OVERVIEW ON THE DETECTION PROGRAMME OF THE CCMAT

Bob Suart
CCMAT, Canada

CANADIAN MINE DETECTION PROGRAM

- Countermine
 - exclusively within DRDC of DND
 - DRES: planning, implementation
 - aimed at Canadian Forces
- Canadian Center for Mine Action Technologies
 - DND, IC, DFAIT partners
 - aimed at humanitarian de-mining

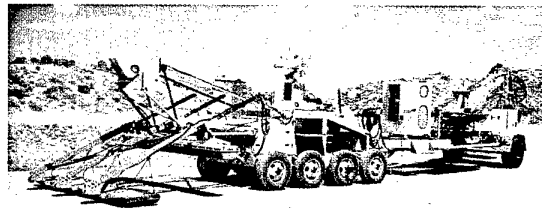
BASIS OF LANDMINE DETECTION PROGRAM

- R&D landmine detection experience since 1977
- Defence R&D Canada
 - study for countermine R&D 1994
- CCMAT
 - detection sub-study published March 1999
 - full study published October 1999

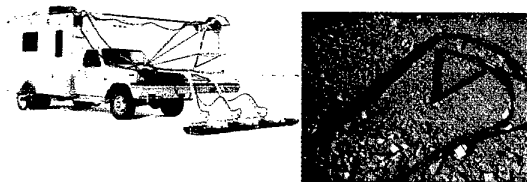
MULTISENSOR LANDMINE DETECTION R&D PROGRAM

- Vehicle-mounted
 - scanning, confirmation, data fusion
- Person portable
 - sweeping, confirmation, data fusion
- Enabling technologies

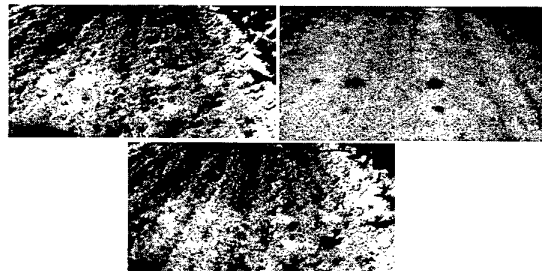
VEHICLE MOUNTED SYSTEMS - ILDP



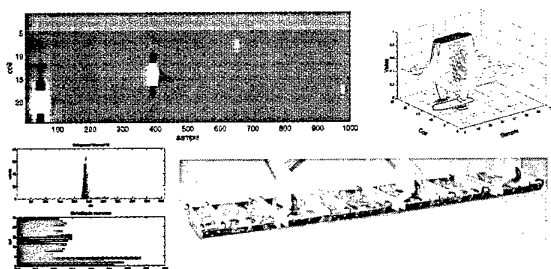
IR PHENOMENOLOGY STUDIES



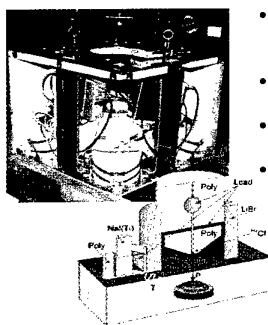
IR PHENOMENOLOGY STUDIES



EMI Array Studies

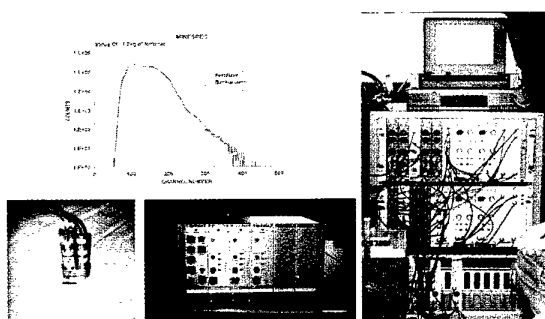


CONFIRMATION: TNA

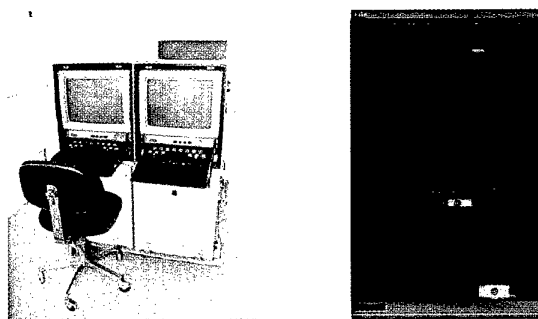


- Can confirm presence of all surface laid or shallow AT mines in few seconds to 1 minute
- AT up to 20 cm deep and large AP mines in < 5 minutes
- Laboratory prototype, not ruggedized
- Has worked well in extreme conditions

TNA-BUILDING A FIELDABLE UNIT



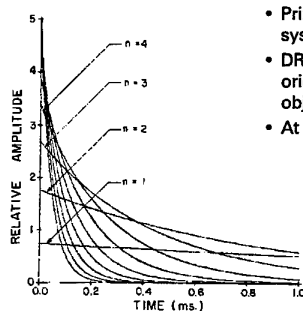
DATA FUSION STUDIES



PERSON PORTABLE SYSTEMS



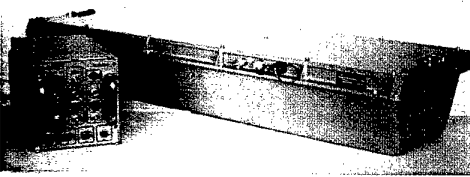
SWEEPING HAND-HELD: ENHANCED METAL DETECTION



- Primary sensor for most fused systems
- DRES has done depth, orientation, ID extraction of metal objects since late 1970's
- At present small in-house effort

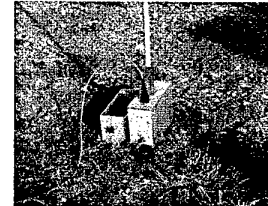
SWEEPING HAND-HELD: GPR

- Original R&D was with ILDP, now aim at handheld
- Small in-house effort
- Have general purpose GPR system
- Will collect data from mines starting summer 2000
- Will investigate soil characterization



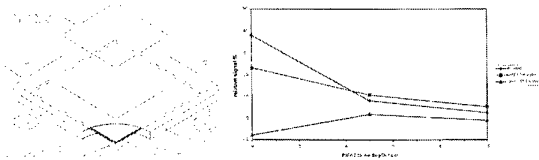
SWEEPING HAND-HELD: X-RAY BACKSCATTER IMAGING

- completed pilot study
- started in-house R&D Fall 1999
- geometry modelling
- investigating detector types



SWEEPING HAND-HELD: NEUTRON MODERATION IMAGING

- feasibility study completed 03/2000
- development of prototype



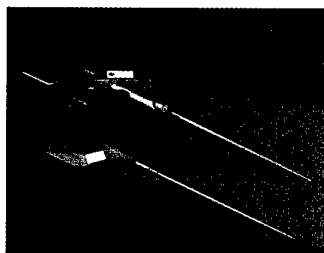
SWEEPING HAND-HELD: OPTICAL TRIPWIRE DETECTION

- Feasibility study complete
 - good results
 - appears feasible
- POC study started
 - 3 years to finish



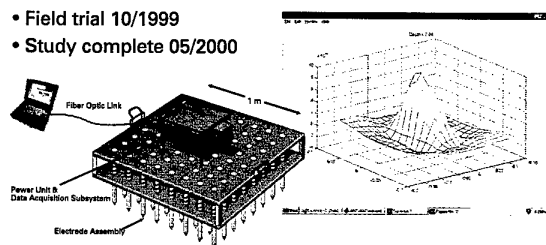
CONFIRMATION: SMART PRODDER

- Started in 1994
- User trial Sep 1999
 - good concept but
 - not acceptable with deficiencies
- Fixing deficiencies
 - complete by 2001
- Extensive testing

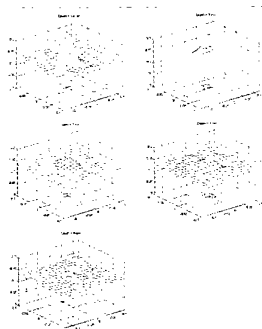
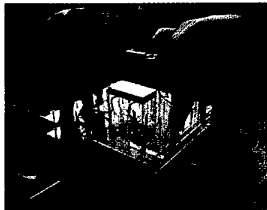


CONFIRMATION: ELECTRICAL IMPEDANCE TOMOGRAPHY (EIT)

- Field trial 10/1999
- Study complete 05/2000

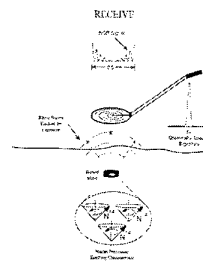


CONFIRMATION: EIT

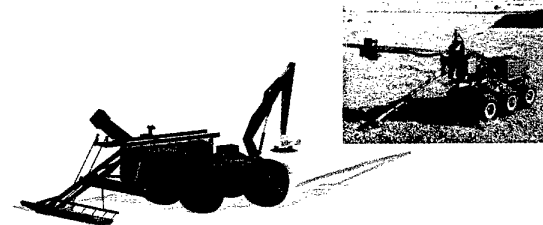


CONFIRMATION: OTHER

- Nuclear quadrupole resonance (NQR)
 - US has extensive program
 - CA will not duplicate effort
 - but could fund gaps if they arise
 - evaluation trial at DRES Summer 2000
- Trace explosive detection (TED)
 - DREV doing migration/concentration modelling and experiments
 - CCMAT funded at very low level
 - CCMAT provided buried mine sites
 - stopped



ENABLING TECHNOLOGIES



TEST AND EVALUATION

- Why?
 - huge number of mine detectors on market
 - de-miners have little performance information
 - need for lab & field tests
 - companies offer many detection systems
 - no quality control

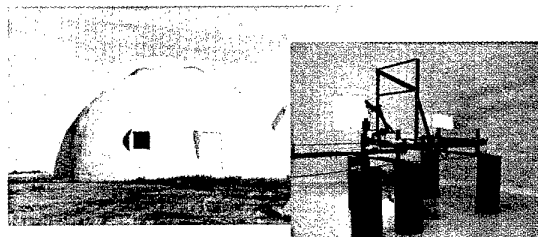


DETECTOR TRIALS

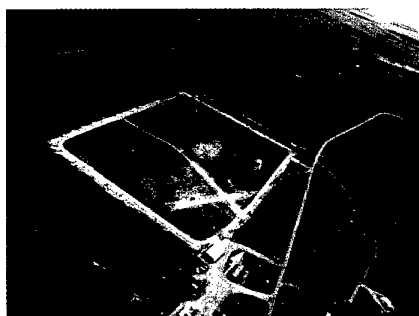
- In theatre: Cambodia, Yugoslavia, Afghanistan
- support to CMAC, UNMAC at DRES
 - solved serious CF detector moisture problem



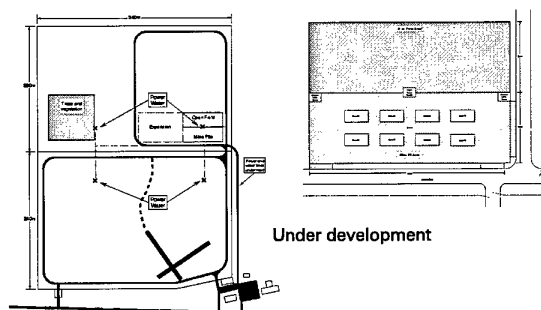
FACILITIES: FOAM DOME



FACILITIES: MINE PEN



FACILITIES: MINE PEN



PROJECTS SUPPORT BY THE EC

Wolfgang Boch
EC, DG INFSO

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Scope of the presentation

1. The IST Programme vision
2. On-going activities from FP4-ESPRIT
3. IST 4th Call- 2000 for proposals on Humanitarian Demining
4. Conclusions

IST: A PARADIGM SHIFT

The IST Programme: a new research paradigm

- From data telematics (3rd FP) to multi-media telematics (4th FP) to ambient intelligence (5th FP)
- Ambient intelligence = *ubiquitous computing + ubiquitous communication + intelligent interfaces* which will allow...
- The realisation of innovative, user-friendly, intelligent and communicating products and systems, delivering leading- edge services and systems for Humanitarian Demining.

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

The Problem

- 110 million APLs in 64 countries
- Casualties are unacceptable (20,000 injured per year, 10,000 fatalities per year, Source: US DOD)
- Speed of clearance (1,000 deminers required to clear 4sqkm/year, Cambodia)
- Uncoordinated actions amongst actors
- Inadequate financial support to HD operations

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

The vision

- Reinforcing the contribution of the European Union, with a particular focus on the support to the Stability Pact Region
- Creating a single framework for EU mine actions
- Supporting RTD actions that accelerate provision of more efficient demining tools

IST: INTEGRATION OF TECHNOLOGY AND APPLICATIONS RTD

IST: a new integrated programme

- All types of research: visionary (FET), generic technologies (KA4), applications (KA1,2,3)
- Visible part of integration = Cross Programme Actions (12% of budget) = "the tip of the iceberg"
- Underlying part: application R&D no longer separates technology research from system integration
- Genuine industrial participation in KA 1,2,3 with a view to exploitation of results

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

On-going Activities (IST managed, launched by Fp4 Esprit) (website: <http://www.cordis.lu/ist/ka1/b4home.htm>)

- Single sensors (mostly hand-held solutions)
- Multi-sensors
- Vehicle -based multi-sensors (sensor array)
- Sensor integration and Data fusion
- Advanced sensors (up to 5 years)

1997/98: 10 RTD projects launched
17 M Euro EU funding

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Sensor technology	FP 4 - HD - RTD projects										FP4 - HD support			
	MACADAM	DREAM	DEMINE	INFELD	HOPE	PICE	MINEREC	GEODE	LOTUS	MINESIEVE	ARIS	SGEX	SEARCH2	MINESIGN
Metal detectors (ELECTROMAGNETICS INDUCTION TECHNIQUES)	x	x		x	x	x	x	x	x	x				
Metal detector Array							x						x	
Active microwave techniques (various Ground Penetrating Radar (GPR))	x													
GPR Array		x	x	x	x	x	x	x	x	x				x
Passive mm wave (Micro/millimeter wave radiometry)	x				x	x								
Passive infrared	x						x	x						x
Polarised infrared		x												x
Fast Neutron Analysis (FNA)										x				

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Constraints for new systems/Lessons Learnt

- New systems must be safer and more reliable than existing ones, an extremely high level of confidence is required (>99.6%)
- False-alarm rate still too high (1/10 of present rate is needed)
- Vehicle-based systems do not perform in all terrain
- Operators are reluctant to adopt new/unproven tools
- New/more sophisticated tools require operators' training/practice (time, money and trust)
- Standardized testing and certification procedures
- Operational procurements
- Systems could meet the requirements of secondary market niches

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Objectives of the IST 4th Call - 2000 Closing 12 June 2000 Key Action I, Action line I.4.2.

- To attract truly innovative proposals
- To boost short, medium and longer term R&D
- To provide safer and more effective tools for humanitarian demining activities
- To increase European know-how
- To interest developers in solutions that lead to a major increase in efficiency
- To strengthen European position in this market

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

IST 4th Call - 2000 Scope of Actions & Budget (AL I.4.2.)

- RTD & D
 - Enhance existing sensors/systems
 - Develop new sensors/systems (e.g. vapour, biosensors)
 - Develop data fusion and pattern recognition
 - Demonstrate newly developed prototypes
 - Generic sensors, addressing other sectors than HD
- EC Funding: 12-15 M Euro

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Critical Issues

- Mine detectors do not exist as such
- The industrial participation is limited and targets mainly individual mine detection
- RTD effort is mainly focused on improving sensors, much less effort goes on detection of explosive emission
- Data fusion for multi-sensor systems is still at early stage
- Mine signature databases are still controversial, their usage requires characteristic responses of particular sensors. These responses cannot be used to design new sensors at low frequency

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Conclusions (1)

- Greater innovation is required
- Greater efficiency and safety is needed
- Target Region (Balkans) is an opportunity to design tools that could be used later in a wider market
- Potential of data fusion still to be demonstrated
- Alternative markets exist, which provide extended customer bases (security, building clearance and wiring positioning, ...)

IST TECHNOLOGIES FOR HUMANITARIAN DEMINING

Conclusions (2)

- Expected Results from IST-2000 Call
 - Improvement of technologies for area reduction (e.g. multi-/hyper spectrum)
 - Demonstration of data fusion for mine detection & localisation - both at test-sites and in-field
 - Development of generic sensors (e.g. biosensors)

THE ROLE OF THE EC'S JRC

Alois J. Sieber
EC, JRC

THE NEEDS

... Commission needs access to high quality, up-to-date and pertinent scientific knowledge to inform its decision. Needs ... To find out on-line the latest state of knowledge

A primary function of the JRC should be to facilitate the gathering and fair assessment of information

Commission needs an independent scientific resource which can develop monitoring systems or new measurement tools either itself, in collaboration with others or sub-contracting

THE JRC MISSION

- to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies.
- As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process,
- it serves the common interest of the Member States, while being independent of special interests, whether private or national

TASKS

Statement of Operational Requirements

- Establishment of SORs for the Balkans in close collaboration with GIC and local Mine Action Centres and with RWG

Standards

for demining equipment, systems, and methods, including GIS

- Inventory of existing standards
- Support to CEN/ISO/UN

TASKS

Test and Evaluation

- **Support to ITEP** (demining equipment, systems, and methods; including individual sensor and mechanical clearing systems)
- **Completing International Pilot Project on MD**
- **Supporting in-field tests**
- **Design of surrogate mines**

TASKS

Demonstration experiments

- First international campaign foreseen in Croatia

Mine field survey

- Assessment of the potential of air- and spaceborne data for identification of mine fields
- Experimental campaign to identify infestation of vegetation by explosives

TASKS

- Extension of the international signature catalogue for mines, environmental components and clutter,
- Creation of multi-sensor data sets for data fusion projects,
- Assessment of the degradation of mines,
- Experimental comparison of signatures of real and surrogate mines,

TASKS
<ul style="list-style-type: none">• Improvement of algorithm for the detection and identification of mines,• Support to the Demining Technologies –Information Forum,• Fostering the Network of Excellence ARIS

TASKS
<ul style="list-style-type: none">• Analysis of working context of demining with a view to improving training• Assessment of new sensors for detecting plastic mines• Support to EEDT• Use of mine databases (CAD, material properties etc) in mine detection

TASKS
<p>Information analysis, GIS and decision support</p> <ul style="list-style-type: none">• Maintenance of EU mine action web-site and databases.• Development of HQ web-based GIS/decision support module for resources planning• Support to "operational requirements" in Balkans (soil, climate, UXO content etc)

BELGIAN PROJECT ON HUMANITARIAN DEMINING (HUDEM) SENSOR DESIGN AND SIGNAL PROCESSING ASPECTS

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<http://www.sic.rma.ac.be>, 12th of July 2000

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Jean.Paul.Salmon@rswo.rma.ac.be

ABSTRACT

The Belgian project on humanitarian demining has been initiated by the Belgian Ministry of Defense and is supported by the Belgian Ministry of Defense and the Belgian State Secretariat for Development Aid. It is carried out in collaboration with laboratories of other Belgian universities, i.e. the "Facults universitaires Notre-Dame de la Paix" (FUNDP), the "Katholieke Universiteit Leuven" (KUL), the "Universiteit Gent" (RUG), the "Université catholique de Louvain" (UCL) the "Université de Liège" (ULg), the "Université libre de Bruxelles (ULB), the "Universitaire Instelling Antwerpen" (UIA) and the "Vrije Universiteit Brussel" (VUB), and it is coordinated by the Royal Military Academy (RMA) [1]. This research project aims at contributing in solving the acute human problem of mine pollution by funding research grants devoted to basic research on mine detection and removal. This paper is restricted on describing the efforts and their results for increasing the knowledge on sensors and on sensor/ground characteristics, for designing new sensors or tuning old ones and for processing the data produced by sensors. Furthermore, it considers the detection as a global process wherein the outputs of the sensors, considered as skilled specialists, are integrated in a fusion operation.

INTRODUCTION

Currently, about 60 million anti-personnel (AP) mines are polluting the environment in about 60 countries. Because mine clearance operations proceed much more slowly than mine laying, the number of polluting mines is still increasing. Humanitarian mine clearance operations must be understood and designed correctly, keeping in mind that their main goal is to provide efficient aid to innocent people, who may be severely injured by this dreadful pollution. Further, the analysis of actual demining campaigns primarily reveals the far too long time needed to clear polluted terrain, a far too large false alarm rate, the threat of plastic mines, difficult to detect by classical means (metal detectors), the large variety of the mine clearance scenarios, depending on the country, the region, the climate and the place of the pollution (houses in villages, roads, agricultural fields, etc).

The important parameters which characterize the mine detection problem are the mine occurrence probability, the detection probability of a given material and the false alarm probability of a given material [2]:

- The *mine occurrence probability* in a given position of a minefield expresses the local mine density of that minefield as well. Obviously, it is impossible to control this parameter because it depends on the terrain reality. Nevertheless, this parameter is very important for assessing the probability of an alarm in a given location of the minefield.
- The *detection probability* is the probability of having an alarm in a given position of a minefield for a given detection material, if there is a mine in that position. This probability gives indirectly a measure of the non-detection probability of that material as well.
- The *probability of false alarm* is the probability of having an alarm, for a given material, in a given location if there is no mine in that location.

The two latter definitions are extremely important to understand the humanitarian demining problem and for designing demining systems.

It is indeed particularly important that the detection probability should be as close as possible to one. It is easy to show that evaluating the detection probability also amounts to evaluate the risk of the occurrence of a mine which has not been detected. This risk is concerned with *human preservation* and is therefore of extreme importance. No such risk is acceptable and it is therefore an absolute requirement that a demining system should decrease the probability of such a risk to the lowest upper bound possible (UN requires 0.4% maximum).

Besides, although one indirectly saves human lives by decreasing the false alarm risk thanks to the acceleration of the demining operations, the false alarm risk is also a question of cost. Indeed, a demining method which minimizes the false alarm rate results in an acceleration of the demining operations which results in a money profit.

Therefore, any demining operation enhancement must result in the highest possible detection probability (close to one) and in the smallest possible false alarm rate and that at the lowest price. Generally, it is accepted that the most efficient way for increasing the detection probability while minimizing the false alarm rate consists in using several complementary sensors in parallel and in fusing the information collected by these sensors.

As a matter of fact, it is imperative to evaluate the detection probability when optimizing the performances of a system. However, the detection probability, as it is defined before, assumes that a mine is present in the considered position. Since, during organized trials, the position of the mines is well known, the condition of the occurrence of a mine in the given position where the performances of a system must be evaluated is always realized. This latter remark is of particular importance because it justifies the organization of trials and the construction of models, to be validated by trials, in order to evaluate the detection probabilities.

Furthermore, assuming in the following as the first approximation that the sensors are independent¹, the detection probability can be maximized by optimizing separately the design of each sensor and of the associated signal processing. Next, it can easily be shown that the detection probability increases if the number of different sensors increases and that maximizing the overall detection probability of a set of independent sensors clearly comes to the same as maximizing the detection capabilities of each individual sensor. This justifies the use of several complementary sensors and of data fusion techniques to increase the detection probability. Among the most cited sensors one finds the metal detectors, the radars and the infrared sensors.

Finally, the false alarm risk, i.e. the probability of having an alarm if there is no mine, cannot be as easily evaluated as the detection probability because of the use of data fusion methods which favor the manual or automatic cancellation of false alarms. Furthermore, it is very difficult to evaluate the risk of false alarm because it is very difficult to define in a general way what is not a mine. In this context, it should be particularly inappropriate that a demining system, whatever it may be, makes decision instead of the final user whose own physical security is involved. Therefore, a well designed system should help the user in the decision making, not by replacing him, but by implementing efficient data fusion methods. For this purpose, methods which are able to deal with uncertainty by making proposals including the doubt to the user seem to be promising.

The rest of the paper tries to fit with the previous reasoning. The first step consists in acquiring knowledge on sensors by means of trials explained in section 2. As explained in section 3, the second step consists in developing models for the description of the ground electromagnetic behaviour, in investigating the capabilities of new sensors (hyper-spectral imagery, nuclear quadrupole resonance, ... and educated rodents) and in enhancing the capabilities of existing sensors (Ground penetrating radars, metal detectors and infrared sensors). The third step means making each of these sensors skilled specialists of their respective domain (e.g. mine metallic content detection for the metal detector), as explained in the section 4.1 which analyses specific preprocessing tools and in section 4.2 which describes some dedicated pattern recognition tools. The last steps sketched out in section 5 consists in fusing the high level information produced by the different experts (the sensors with their dedicated processing tools).

¹ the independence is a particular case of the complementarity: two independent sensors are complementary, but the contrary is not necessarily true.

OUTDOOR TRIALS

Realistic dummy minefields have been installed in the RMA, in MEERDAAL and LEOPOLDSBURG by the Belgian Bomb Disposal Unit (SEDEE/DOVO) and the RMA. Fig. 1 shows the experimental setup of the infrared (IR) trials on the minefield of MEERDAAL and a view of the four lanes (natural soil, sand, gravel and sand+gravel) where the mines and the false alarms are laid. The infrared images data were taken every 15 min during 24 hours in two spectral bands (3-5 μm and 8-12 μm) parallel to the ground surface, to avoid interfering reflections. Fig. 2 presents samples of data in the 3-5 μm band and fig. 3 in the 8-12 μm band. These data, collected on 5 CDROM's, are available on the JRC website. These trials were organized with the help of the technical service of the Belgian Army (DTT).

Several Ground Penetrating Radar (GPR) experiments organized by the RMA (ELEC) also took place, particularly with the RAMAC, the SIR2 and the ERA GPR's². The results stored on CDROM are available on the JRC website.

More than 400 AP mines, whose explosive has been replaced by an equivalent non-explosive product, were laid in LEOPOLDSBURG. The minefield layout (known with a precision of 2 cm measured by the Astronomy and Geodesy Department of the RMA), has been chosen in order to mimic existing tactical configurations and is ready to be used for airborne minefield detection. The minefield of Leopoldsburg has been used as a test minefield by the DGVIII pilot project on airborne minefield detection in Mozambique. Fig. 4 gives the same scene of the minefield in different spectral bands. The photograph on the left, provided by the Aerodata company, shows a general view taken with an infrared (near infrared) film with a ground resolution of 2 cm. The two photographs on the right, provided by the Eurosense company, are taken with a colour infrared (near infrared, red and green) film with a ground resolution of 3 mm. The first one is a general view, the second one shows a high resolution view of an anti-tank mine.



Figure 1: Meerdaal IR trials.

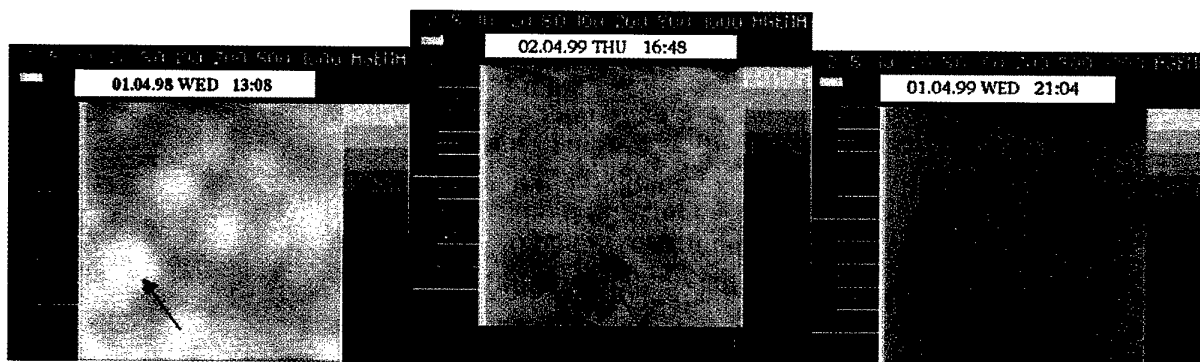


Figure 2: Meerdaal IR 3-5 μm data.

² Respectively from Malå Geosciences (SW), Geophysical Survey Systems, Inc (GSSI) and ERA technology, UK.

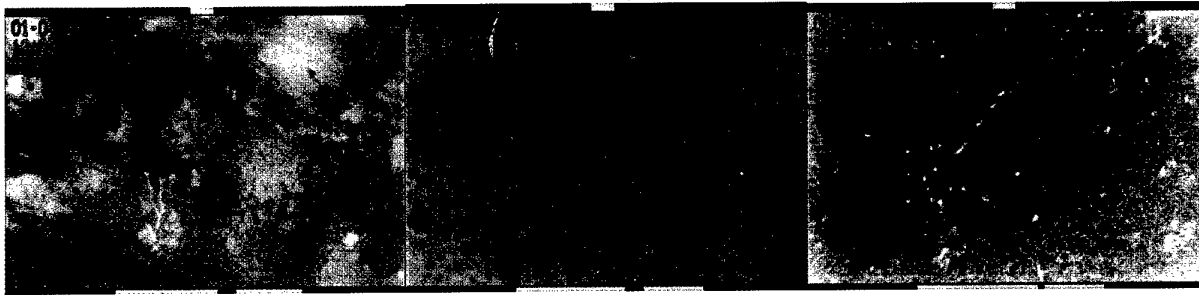


Figure 3: Meerdaal IR 8-12 μm data.

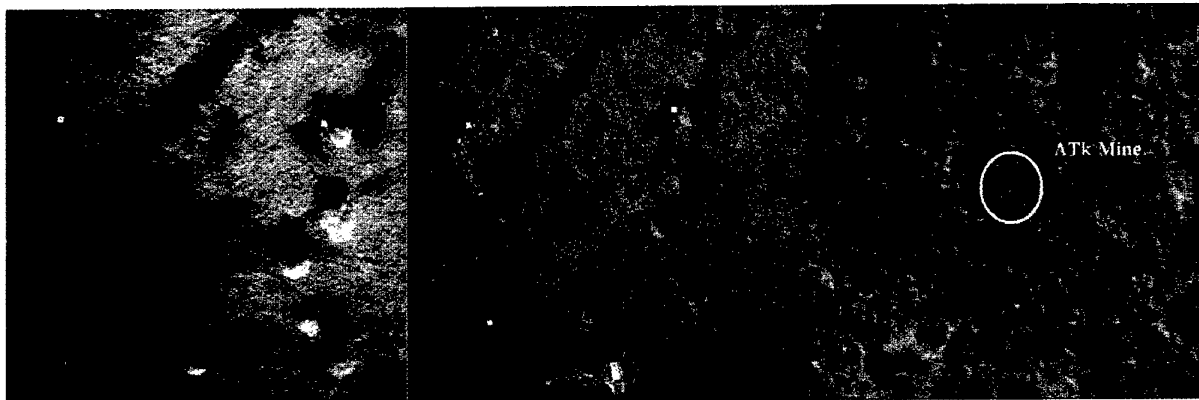


Figure 4: Leopoldsburg minefields.

SENSOR DEVELOPMENT AND ANALYSIS

Educated rodents

Actually, one of the most efficient “sensor” for mine detection is the dog. But it seems that rodents are easier to educate and to feed and that they can work longer than dogs. Furthermore, the rodents are much lighter and have a better olfactory capacity and a better immunity. The non profit organization APOPO and the UIA are currently making tests in educating rodents and have already booked interesting results.



Ultra-wide band (UWB) ground penetrating radar (GPR)

Useful definitions to understand what follows have to be given first. A A-scan is a one-dimensional signal taken perpendicularly to the ground surface and is the basic echo signal produced by a GPR. A B-scan is a two-dimensional signal resulting from a collection of adjacent A-scan along a straight line horizontal to the ground surface. A C-scan is a two-dimensional horizontal slice (parallel to the ground surface) in a set of adjacent B-scans.

Soil characterization

Ground penetrating radars and passive radiometers are intended as anti-personnel mine detectors. Their performances depend upon parameters such as type and texture of soil, soil water content, soil density and operating frequency. In order to evaluate the performances of microwave technologies in land-mine detection, the electrical properties of soils have been extensively evaluated by the Microwaves Laboratory of the UCL from 2 to 18 GHz both theoretically and experimentally, using a new transmission method, as a function of soil type and water content. This has resulted in a new model for the microwave permittivity of soils, valid over a wide frequency range as shown in [3].

UWB antennas development

The Electrical Engineering and Telecommunication Departments of the RMA has developed small-sized ultra-wide band TEM horn silicon-filled antennas with a frequency range from 1 GHz to 7 GHz ([4], [5] and [6]). The maximum size of these antennas does not exceed 12 cm. Thanks to the use of a pulse generator with a rise time of 45 psec, of a computer controlled digitizing oscilloscope and of a computer controlled X-Y gantry on which the emitting and the receiving antennas are fastened, it is possible to record the A-scans, B-scans and C-scans which are needed for our project and for optimizing the antennas. Fig. 5 shows two of the antennas which were used for the tests and a sample A-scan of a PMN mine in loam. Fig. 6 presents two B-scans of a PMN mine respectively in loam and in sand and a C-scan of a PMN mine in loam at 4 cm depth.

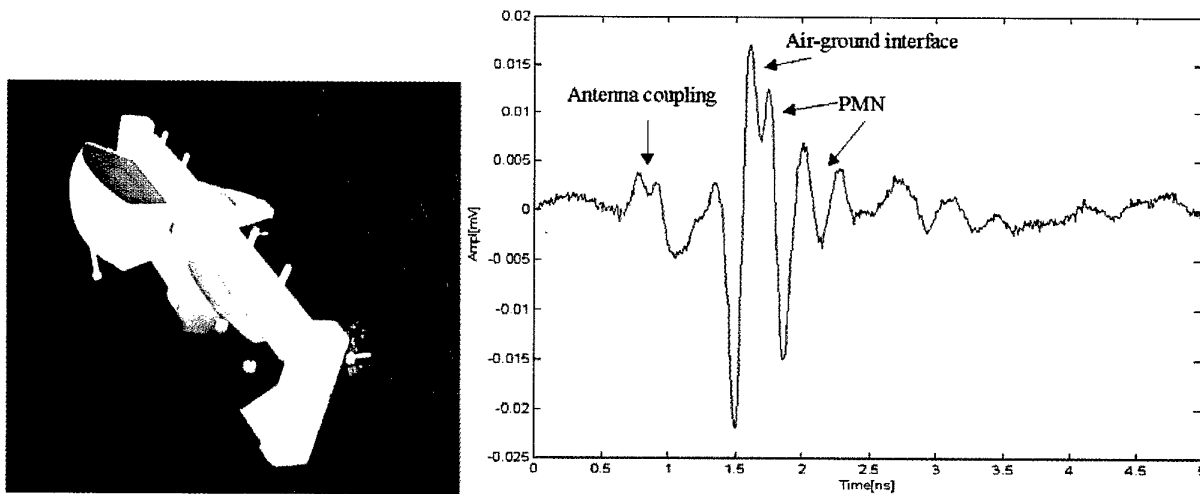


Figure 5: Antennas and an example of a PMN A-scan in loam.

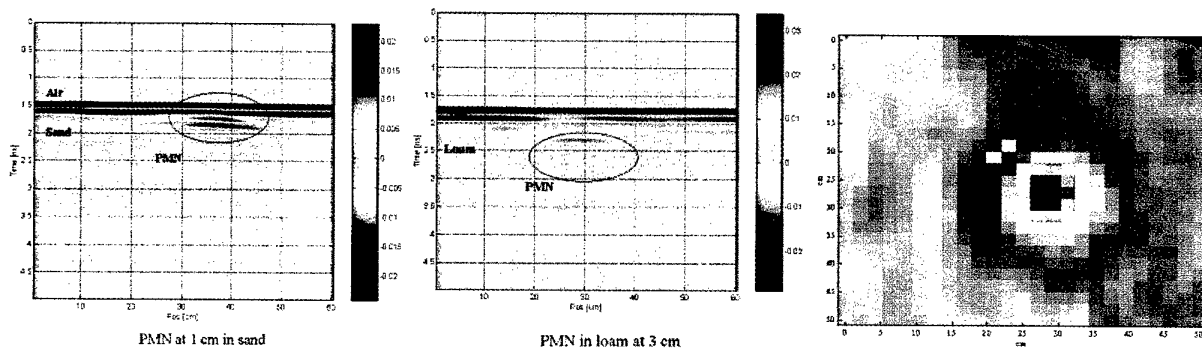


Figure 6: from left to right, PMN B-scans in sand and in loam and a PMN C-scan in loam.

Modeling emitted IR radiations

Because it is impossible to control the IR environment (position of the sun, sky radiance, air temperature, background reflections and emissions, etc), it has been decided to design a simple model that gives information on the temperature evolution on the surface of the ground above anti-personnel mines and its surroundings in order to be able to answer questions like “why, when, where and which thermal IR sensors to use?”. Only thermal conduction has been analyzed. The model is based on the general equation of heat conduction with specific assumptions (symmetry, simplified shapes, constant parameters, etc). A numerical model, based on a finite volume method, has been developed in Excel and can be very easily modified for a set of different parameters such as mine shape, soil type and depth. This work was done by the ULB with support of the RMA and the VUB (see [7] and [8]).

Hyper-spectral images

In the context of this project and of a collaboration between the Interuniversity Microelectronics Centre (IMEC) and the RMA, taking into account the very selective properties of the material reflectivity, it has been possible to demonstrate the capabilities of wavelength tuning for discriminating different materials. Very narrow wavelength bands have been used in laboratory experiments. Examples of results are given on the figures below. Fig. 7 shows the used test box, filled with sand. On the sand surface a plastic foil, an integrated circuit and a piece of metal have been placed. On fig. 8, from left to right with increasing wavelength, one sees appearing first the plastic foil, afterwards the integrated circuit and finally the piece of metal [9].

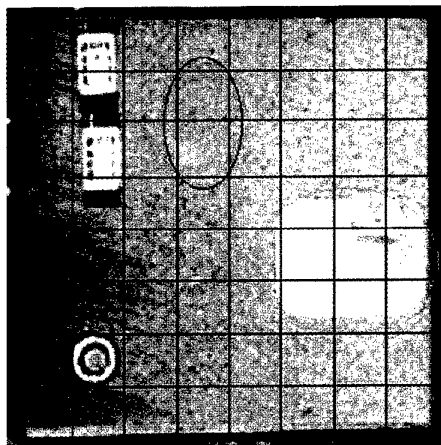


Figure 7: Hyper-spectral imagery: test box.

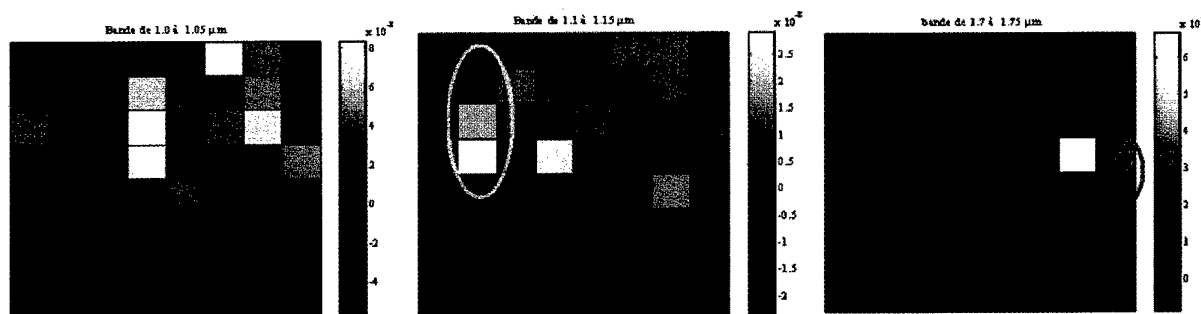


Figure 8: 1.00-1.05 μm (plastic) - 1.10-1.15 μm (IC) - 1.7-1.75 μm (metal).

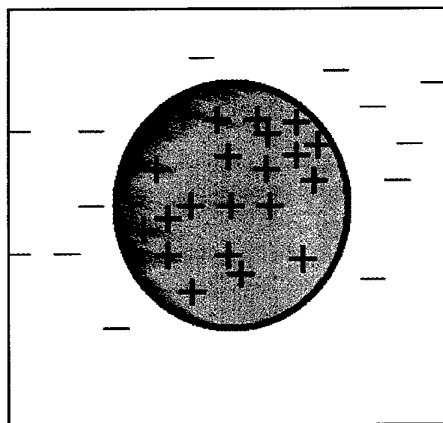


Figure 9: quadrupole moment.

Nuclear quadrupole resonance

Advanced Nuclear Quadrupole Resonance (NQR) techniques can be used to detect explosives in any surroundings. The quadrupole charge distribution of the atom results in alignments of nuclear spins. A radio frequency pulse (rf-pulse) generated by a transmitter coil causes the excitation of nuclear spins to higher quantized energy levels. When the nuclear spins return to their equilibrium position, they follow a particular precession frequency. This specifies the atoms and functional groups in the molecules. Nitrogen is a quadrupole atom that appears in every type of explosive. Because of very distinct NQR frequencies the false alarm rate due to other nitrogen containing materials is extremely low [10]. The study of this type of sensor results from a collaboration between the King's College in London, the RMA and the KUL. Fig. 9 and 10 below give an idea on the NQR process.

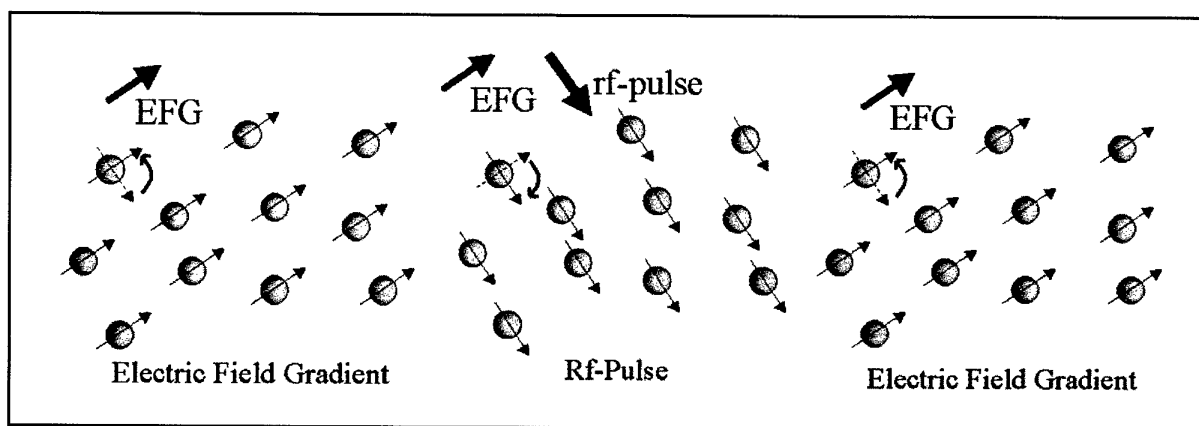


Figure 10: Detection process.

SIGNAL AND IMAGE PROCESSING

The aim of this section is to show how to build skilled specialists from each raw sensor, using signal processing techniques. The first subsection addresses the problem of the signal conditioning or preprocessing, i.e. signal detection, noise reduction, signal restoration and enhancement which is a very important step before further processing. The second subsection deals with the problem of recognizing the signal content by applying pattern recognition techniques aiming at increasing the expertise of each sensor separately.

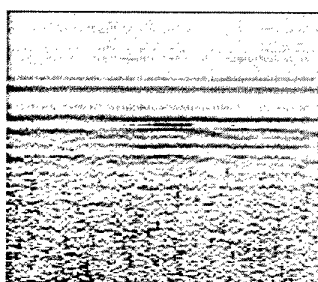
Data preprocessing - noise reduction & restoration

GPR data preprocessing

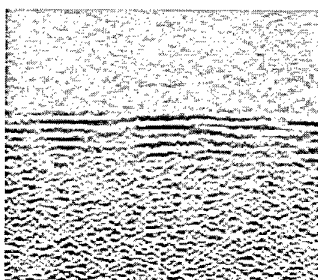
In the case of GPR signals, A-scans and B-scans were studied. Useful signals, i.e. containing useful information, can be extracted and the signal to noise ratio of objects detected in A-scans or B-scans has been enhanced. In this context, the VUB

has developed [11] a method for signal detection in A-scans using hypotheses test (signal is background/signal is useful) after having removed a mean A-scans from the B-scan.

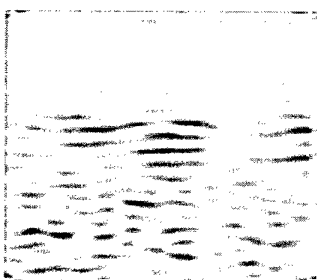
The RUG has been investigating [12] the applicability of multiresolution decomposition techniques to remove the background of GPR images with buried mines. The second image of fig. 11 shows the result after horizontal filtering, which means simple subtraction of the average trace from each row. The third and the fourth images are the reconstructed version by the multiresolution scheme with a non-separable filter and a separable filter respectively. In the same order of idea, the RMA has selected matched filters using the wavelet transform for enhancing the target/background contrast. One sees on fig. 12 that a filter around 1 GHz discriminates very well the



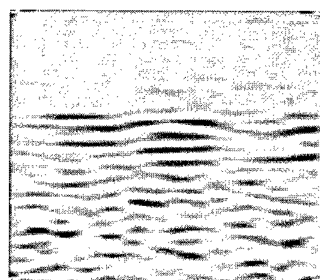
Original GPR image



After background removal



Pyramidal reconstruction
with nonseparable filter



Pyramidal reconstruction
with separable filter

Figure 11: GPR B-scan - original image - background removal experiments.

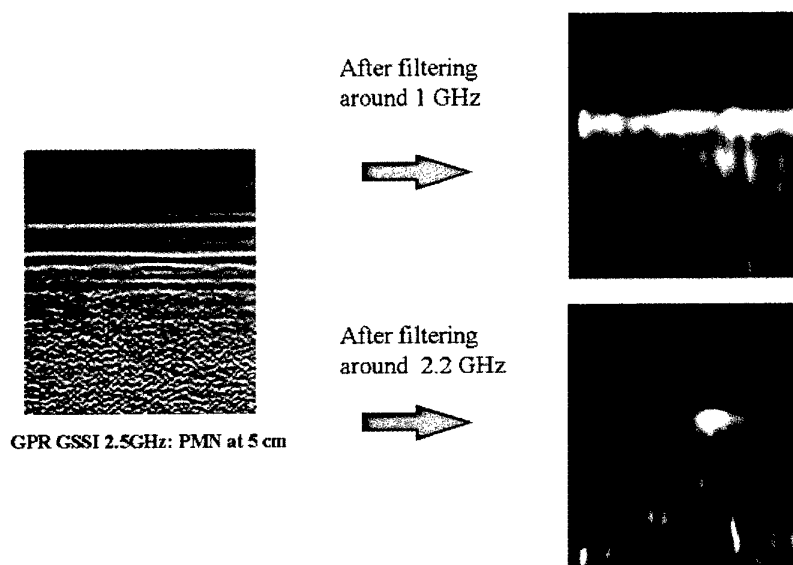


Figure 12: GPR B-scan - separation of ground-air interface from mine response.

air/ground interface (top image) and that a filter around 2.2 GHz discriminates successfully the buried AP mine (bottom image).

The analysis of a sequence of C-scans by means of the Karhunen-Loève transform has been done by the VUB [13] and produces also interesting results. Fig. 13 shows the obtained results. On the left side, sample C-scan images of the sequence are presented. On the right side, the four most significant images (with the largest variances) after the Karhunen-Loève transform are presented.

The processing of the absolute value of A-scans using the Hilbert transform has been done by the

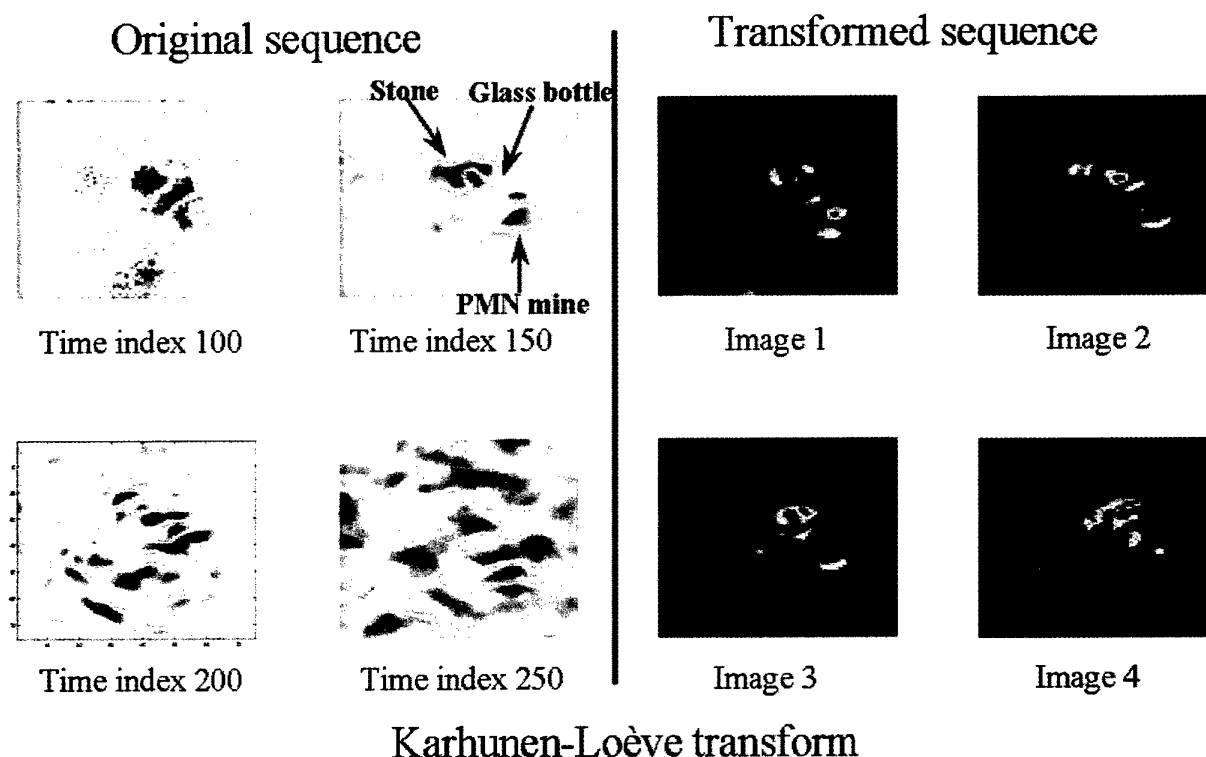


Figure 13: GPR: Principal component analysis of a C-scan sequence.

RMA in order to obtain the A-scan envelopes and to enhance the resulting C-scans. The results obtained with this method are shown on fig. 14.

RMA ([14]) has decomposed A-scans in a linear combination of wavelets. A limited number of wavelet coefficients (typically 5 coefficients) is sufficient to represent A-scans with a good resolution. The selected wavelet is derived from the emitted radar impulse. The results are shown on fig. 15.

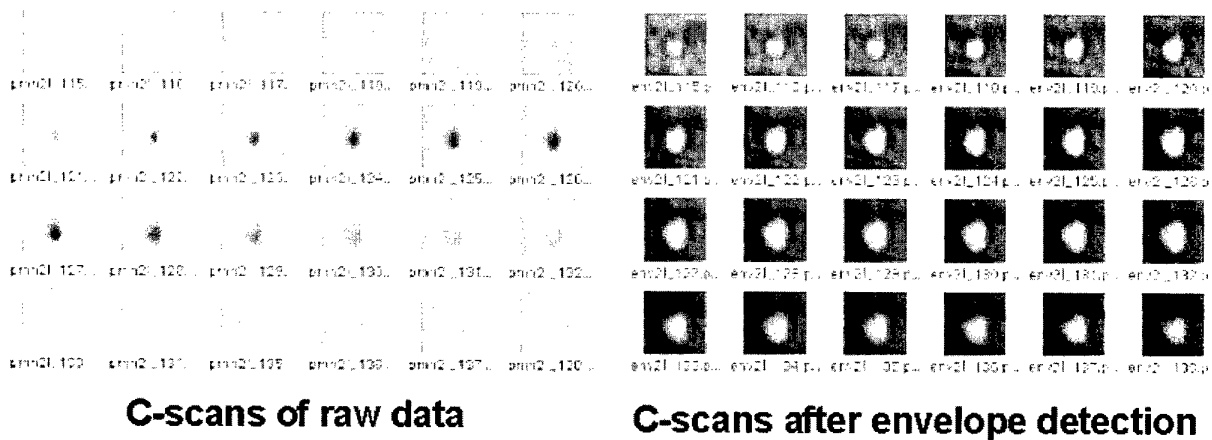


Figure 14: GPR: enhancement of a C-scans sequence using the Hilbert transform.

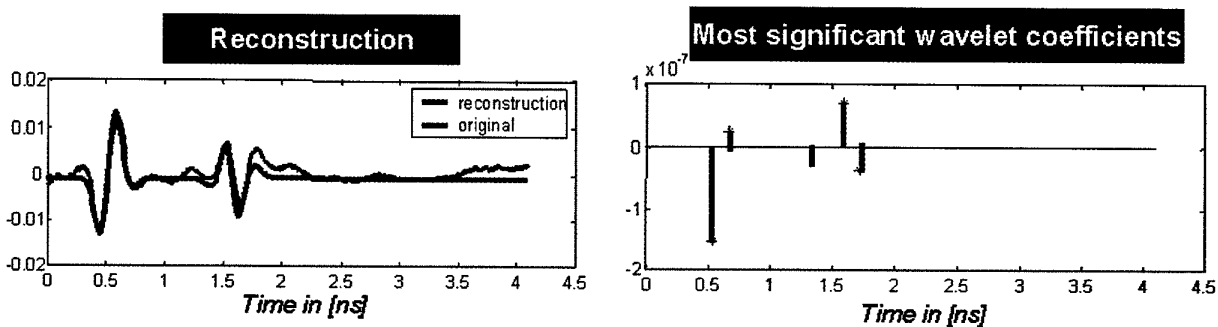


Figure 15: GPR: representation of A-scans with a limited number of wavelet coefficients.

IR data preprocessing

An efficient denoising method in the wavelet domain has been proposed by the RUG [15]. This method adds spatial constraints to the criterion for selecting noisy wavelet coefficients and for each coefficient the probability of being noise-free is computed. The spatial constraints are derived from prior geometrical assumptions expressing the fact that meaningful wavelet coefficients appear in spatially connected clusters, at the location of characteristic image features like edges, corners, etc. For the criterion itself the magnitudes of the wavelet coefficients are used. Fig. 16 summarizes the results. The top images are the IR original images, the two last ones being processed using histogram equalization techniques. The bottom images are their respective restored versions.

Figure 16: original IR images, with histogram equalization for the 2th and the 3th images (top images) - corresponding restored IR image (bottom image).

The analysis of an IR sequence by mean of the Karhunen-Loève transform or the Kittler-Young transform, which as a matter of

Mine buried under 5 cm of gravel

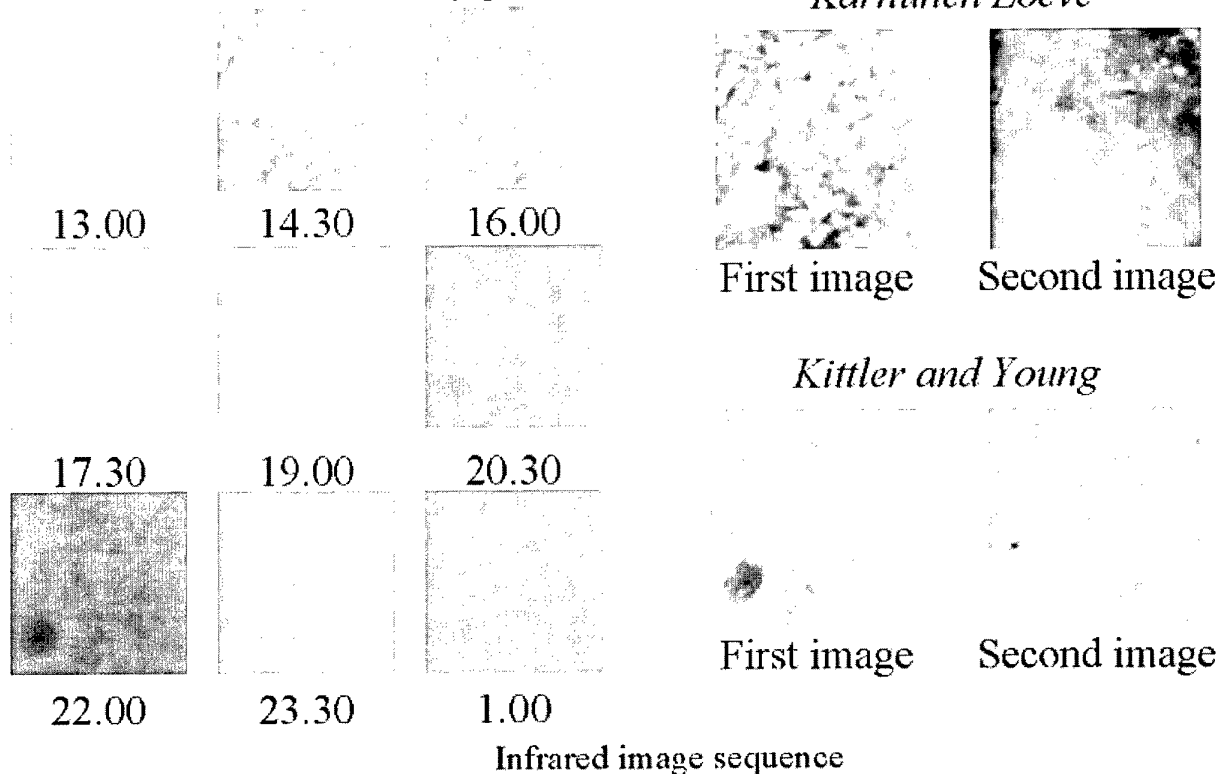


Figure 17: Karhunen-Loève and Kittler-Young transforms.

fact requires a learning phase, leads to interesting results [8] as well. Fig. 17 shows the obtained results. On the left side, sample IR images of the sequence are presented. On the right side, the two most significant images (with the largest variances) after transformation are presented for the two transforms.

Metal detector image preprocessing

Surprisingly, the metal detector, which is the most common detector, considered as an imaging device, can also provide very useful information on the shape of metallic pieces included in mines. Trials have been performed in the RMA [16] by placing the Vallon metal detector on a gantry. Thanks to the collaboration of Vallon, the metal detector is provided with a digital output. The obtained images were processed as follows: after noise reduction using a regularized Wiener filter, the images were deconvolved using respectively an experimental point spread function (PSF), recorded using a small metallic ball, and a simplified theoretical model of the PSF, calculated from the detector head shape. From left to right, fig. 18 shows successively the original image, the experimental PSF and the result after deconvolution. Fig. 19 shows the same but using the theoretical PSF.

A practical example, using the exercise mine PRB409 which has a diameter of 7.5 cm, is shown on fig. 20. The image on the left is the original one. The central image is a RX photography of this mine where one sees clearly a small horizontal metallic cylinder on the right side. The image on the left shows the deconvolved image where the metallic cylinder clearly appears.

Unfortunately, the PSF of a metal detector is a function of the depth and the image formation process is non linear. However, it has been shown by the RMA team that it is possible to derive the depth of a buried object from the original data and thus to derive the corresponding PSF to allow a correct deconvolution. This subject is always under investigation. This interesting consideration shows that the metal detector, known as a cheap mine detection system, is still a promising device.

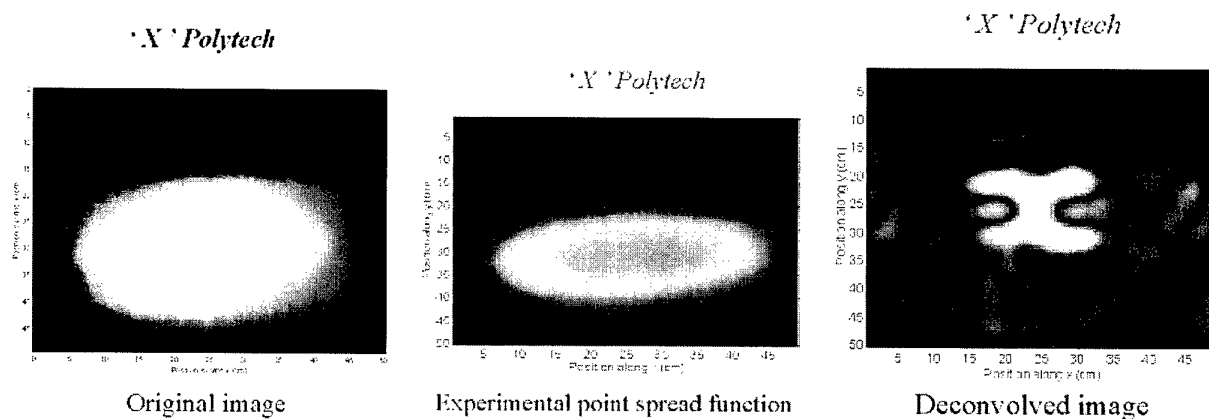


Figure 18: Metal detector - deconvolution with experimental PSF.

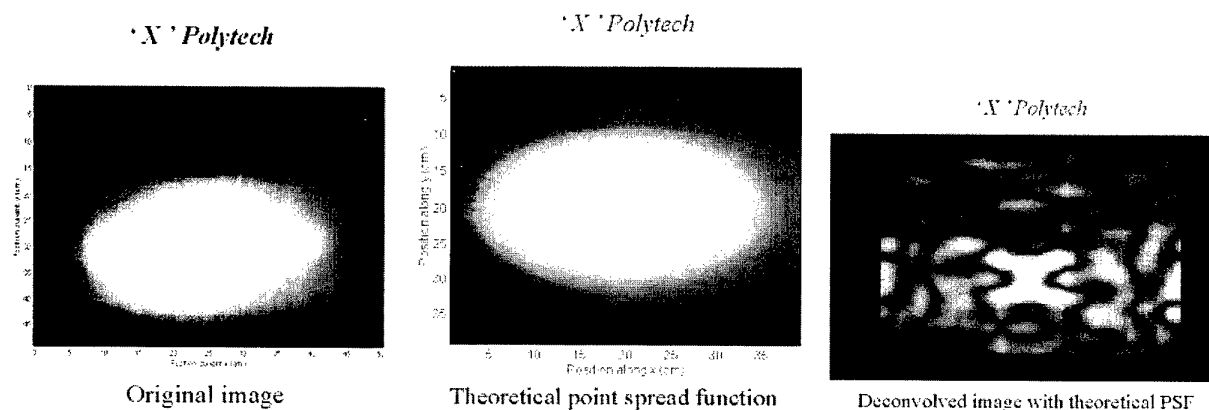


Figure 19: Metal detector: deconvolution with theoretical PSF.

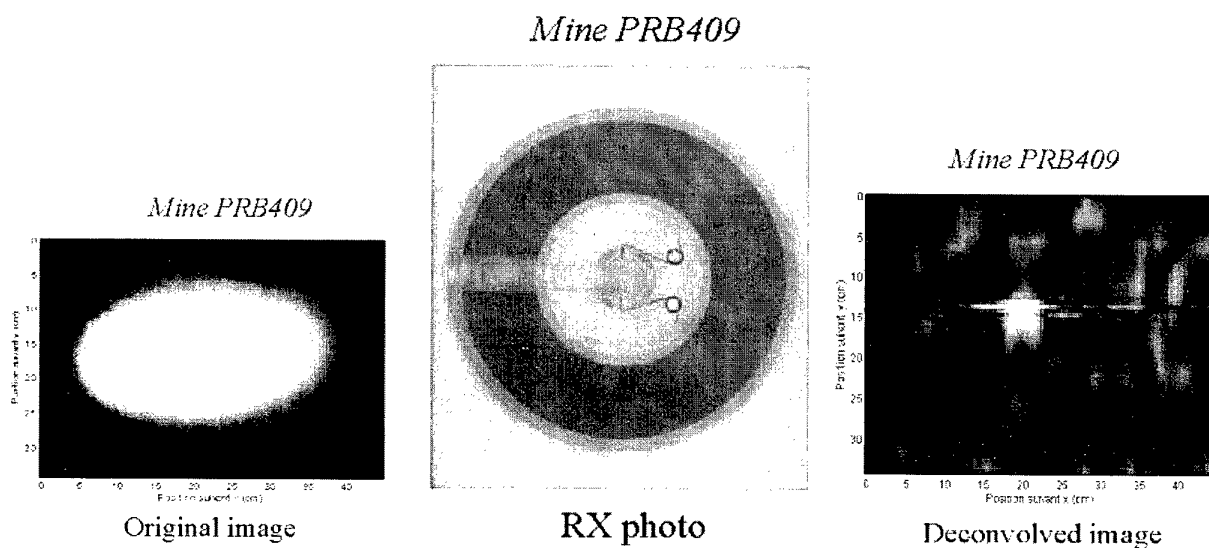


Figure 20: Metal detector - PRB mine deconvolution.

Mine detection expert development

After the signal conditioning, the next step consists of applying pattern recognition methods to the preprocessed data of each sensor in order to get a semantic description of the data information content.

GPR expert

The approach used by the RMA to all three experts (MD, GPR and IR) is to extract from their data information about shape of objects [17].

In the case of GPR, on each of C-slices simple preprocessing (including edge detection) is performed and important edges are extracted. These edges from all C-slices are then put together either on the same 2D image (on fig. 21³ edges from the same depth, i.e. same C-slice, are presented by same colour) or on the 3D image, taking into account which C-slice presents which depth. If the A-scan envelopes are detected using the Hilbert, as previously explained, the results are much better (RMA work) as it can be seen on fig. 22.

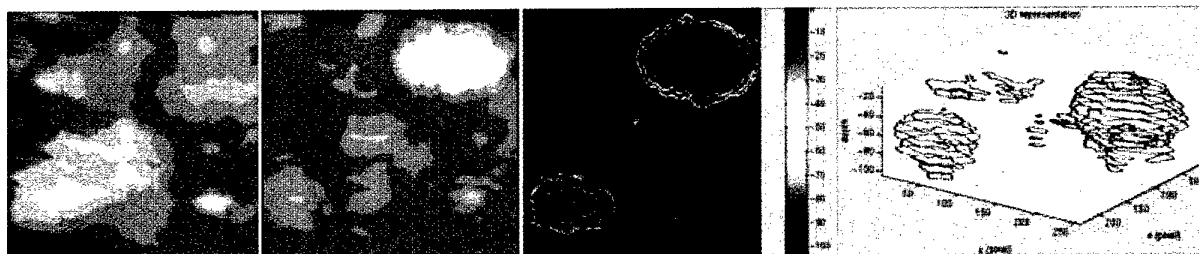


Figure 21: From left to right, two C-slices followed by a 2-D image of edges from all C-slices, where colour is a label of depth, followed by a 3-D image of edges.



Figure 22: From left to right: view of a mine, 3-D GPR image of the same mine.

In order to recover the correct 3-D shape of buried objects, RMA ([14]) has developed algorithms based on the convolution, by modelling the behaviour of the GPR in the time domain. The developed algorithms are faster than the classical migration methods and provide very good results as it can be seen on fig. 23.

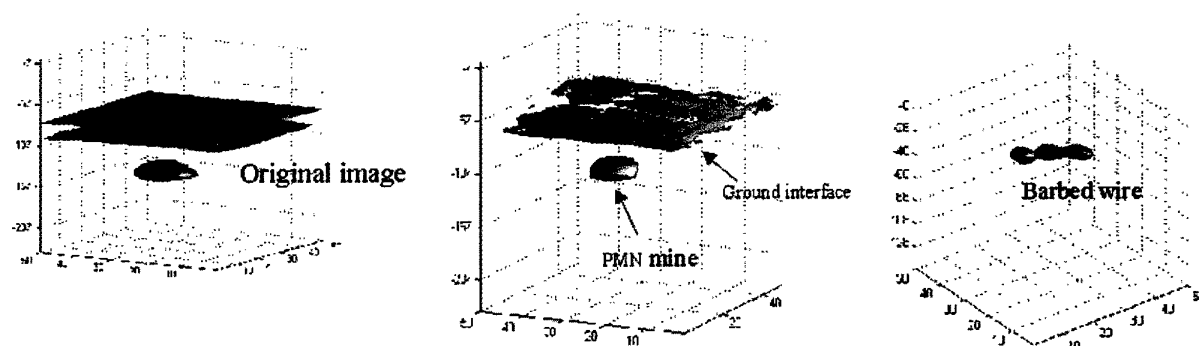


Figure 23: From left to right: raw GPR 3-D image of a PMN mine, restored 3-D image of a PMN mine and restored 3-D image of a 10 cm barbed wire with three barbs.

³ Data provided by ERA Technology, UK.

The VUB has developed a classification method for ultra-sonic and GPR signals [11]. The method first consists in extracting features (the time signal itself, its Fourier transform, its auto-correlation, its wavelet coefficients, its Wigner-Ville transform and the derived scattergrams of the latter). After a selection of the most discriminant features, a supervised parametric approach based on the Bayes optimal classifier and which requires a training phase, is used. Two classification methods have been tried: the first one only implements one classifier making use of all the selected features, the second one uses a hierarchically organized multi-classifier system, combining the conditional probabilities computed by specialized classifiers either by averaging them or by multiplying them.

The obtained results are described on fig. 24. The GPR data of these tests were provided by the DETEC laboratory of the "Ecole polytechnique fdrale de Lausanne" (Suisse).

IR expert

For images taken by infrared cameras, the RMA has performed a simple preprocessing, followed by edge detection. Since most of the mines are circular, they will be ellipses on binary, edge detected images; because of occlusion and noise, these ellipses are not, in general case, continuous. Therefore, The RMA develops shape recognition tools that are able to detect partially occluded ellipses [17]. Two examples of obtained results are shown on fig. 25.

Metal detector expert

Taking into account that there are also some mines that do not have regular shape, the RMA is analyzing possibilities of recognition of arbitrary shapes [17]. Furthermore, in the case of metal detector and plastic mines, just a small metallic part inside such a mine (e.g. fuze) will be detected, and their shape does not have to be elliptical. An example is given on fig. 26 below, where detection of X shape is performed.

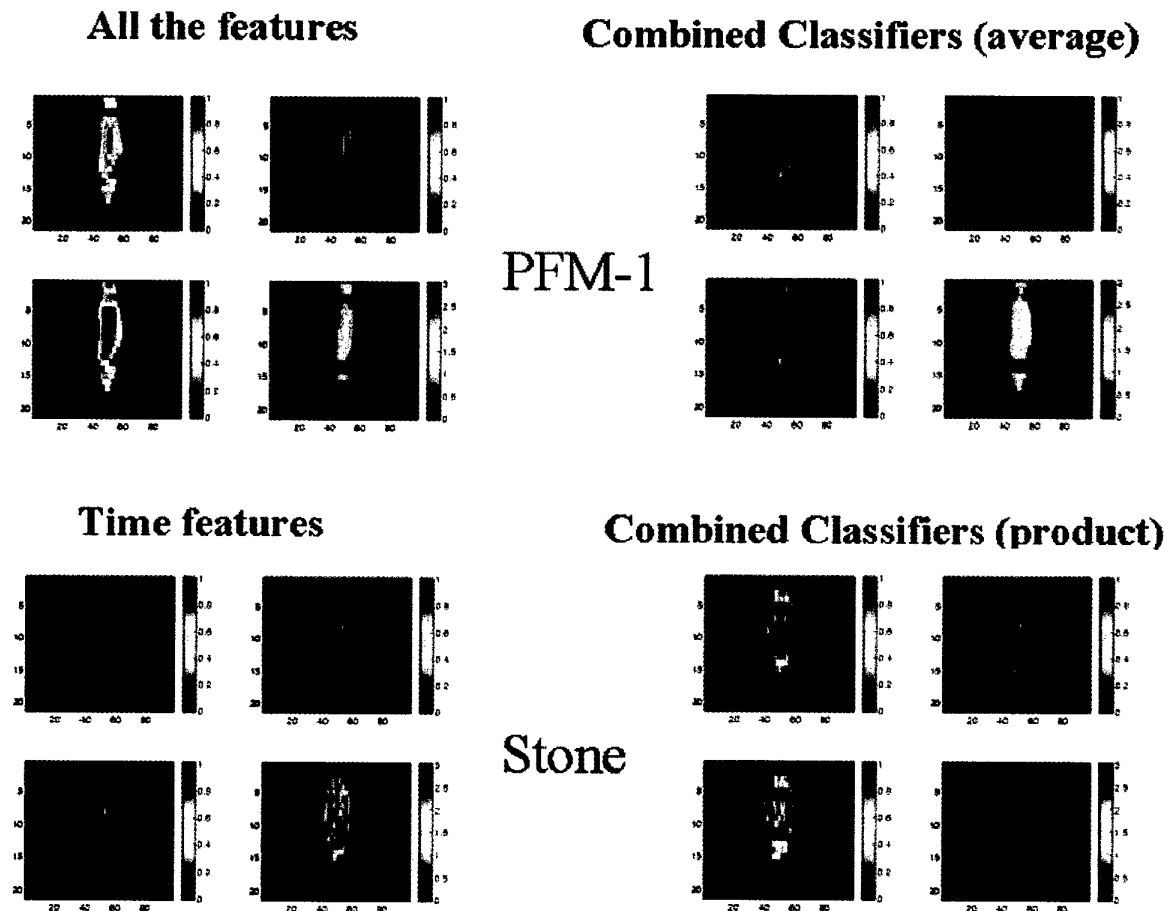


Figure 24: GPR: Classification of a stone and of a PFM-1 mine in the ground from C-scans.

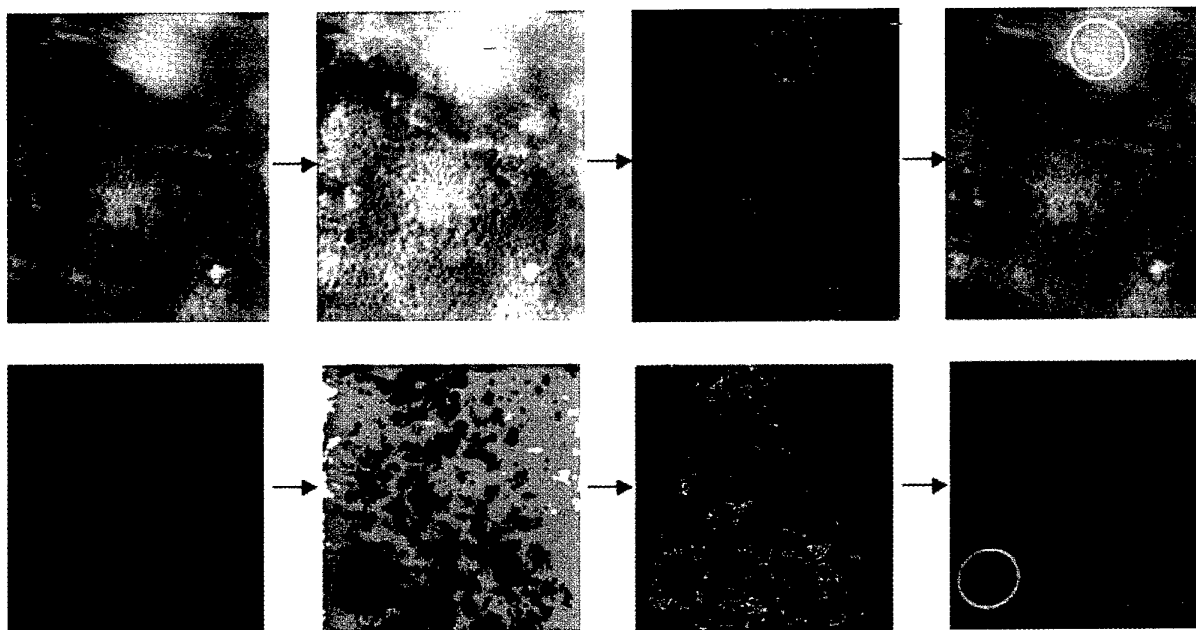


Figure 25: From left to right: the original image followed by the preprocessed image, the detected edges and the original image with detected mine-like shape (ellipse).

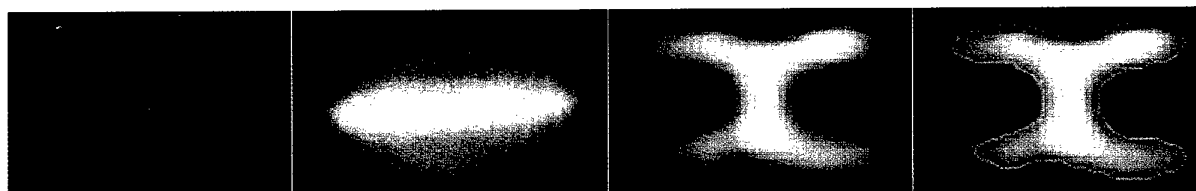


Figure 26: From left to right, photograph of the measured X shape, the output of the metal detector, the deconvolved output on the detected shape.

EXPERT FUSION

The principles of operation of imaging metal detector, GPR and infrared camera, their complementary information, factors that affect their operability lead to the conclusion that their fusion should result in improved detectability and reduced number of false alarms in various situations (different types of mines, of soil, vegetation, moisture, etc.). Therefore, we have been analyzing possibilities to combine these three sensors, but the model we have been developing is quite general, i.e. it can be easily modified to include other sensors as well. Since in this domain of application we have to deal with uncertainty, ambiguity, partial knowledge and ignorance, we choose an approach where they can be appropriately modelled, and that is: belief functions within the framework of Dempster-Shafer theory. A main motivation for working within this framework is to be able to easily model and include existing knowledge regarding: chosen mine detection sensors, mine laying principles, mines, and objects that can be confused with mines.

In order to illustrate our approach, let us analyze a very frequent case in reality - detection of high-metal content objects. Since all three sensors give images, i.e. information about size of an object, the following four classes create the frame of discernment Θ :

- MMR (metallic mine of regular shape),
- MMI (metallic mine of irregular shape),
- MFR (metallic friendly, i.e. non-dangerous, object of regular shape),
- MFI (metallic friend of irregular shape).

Furthermore, the criteria that can give the most information about the real identity of the object in this case, for our knowledge, are the following:

- for each of the three sensors:
 1. ellipse fitting, that is, how well the shape of the object fits in an ellipse, assigning masses to subsets {MR, FR}, {MI, FI}, Θ ;
 2. shape elongation, again giving masses to {MR, FR}, {MI, FI}, Θ ;
 3. area/size, by which information about expectable size range of mines is included, assigning mass mainly to Θ within that range, and to {FR, FI} elsewhere;
- for MD: burial depth, including the knowledge about the depths where mines can be expected, so, again, assigning masses to Θ and {FR, FI};
- for GPR;
 1. depth dimension of the object, that gives, similarly as information about area, masses to {FR, FI} and to Θ ;
 2. comparison of the depth position of metal detected by MD and the object depth interval sensed by GPR; if they are in accordance, masses are assigned mainly to Θ , if they are not, a largest part of masses should go to subset {FR, FI}.

The masses are defined as functions depending on measure of ellipticity, elongation factor, area, depth, respectively. They are detailed in [18]; see also example in Figure 1.

After assigning masses for all sensors and all criteria, we combine them using well-known Dempster's rule in unnormalized form 9 in order to preserve potential conflict between sensors). After that, guesses about the real identity of object under observation are made, on the basis of the strength of belief assigned to each subclass of the frame of discernment. This list of guesses is served to a deminer, together with confidence degrees, as well as processed data of each sensor, in order to help him in making his final decision.

CONCLUSIONS

This paper aims at giving the present state of the Hudem project by describing the efforts and their results for increasing the knowledge on sensors and on sensor/ground characteristics, for designing new sensors or tuning old ones and for processing the data produced by sensors. Furthermore, it presents the detection as a global process wherein the outputs of the sensors, considered as skilled specialists, can be integrated in a fusion operation. The future work includes the further development of the sensor investigation and design, the enhancement of the signal preprocessing methods, the improvement of the dedicated expertise of each sensors and the development of associated effective data fusion methods. This implies as well trials in a multisensor environment which will be conducted in a near future.

ACKNOWLEDGMENT

The authors wish to thank all the researchers of the HUDEM project without whom it was impossible to write this paper. In spite of the difficult current international situation, it was possible for our foreign researchers to find the necessary resources for providing an excellent work and for maintaining an enthusiastic spirit of collaboration. They think particularly to N. Milisavljevic, A. Pizurica and D. Milojevic. They also wish to emphasize the excellent work performed by the Belgian researchers, A. Engelbeen, M. Storme, B. Scheers, L. van Kempen and B. Weetjens. They also wish to thank Prof I. Lemahieu, Prof. W. Philips, Prof. P. Van Ham, Prof. J.A.S. Smith, Prof. Van Hecke, Prof. A. Vander Vorst and Prof J. Cornelis for the support they provide to the researchers.

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THE UK RTD PROGRAMME

David Parkes
DERA, UK

SUB-SURFACE TARGETS

- **Military**
 - Mines both AP and AT
 - Arms Caches
 - Bunkers
 - Pipelines
- **Non Military**
 - AP Mines (Well Known Humanitarian Clearance Problem)
 - Infra Structure (Pipes, Cables, Sewers, Optical Fibre Links)
 - Breast Tumours



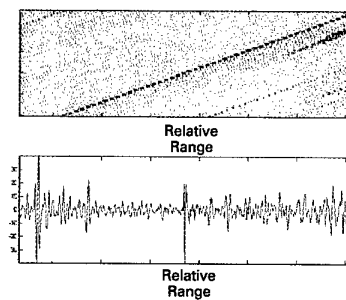
MINDER Research Vehicle

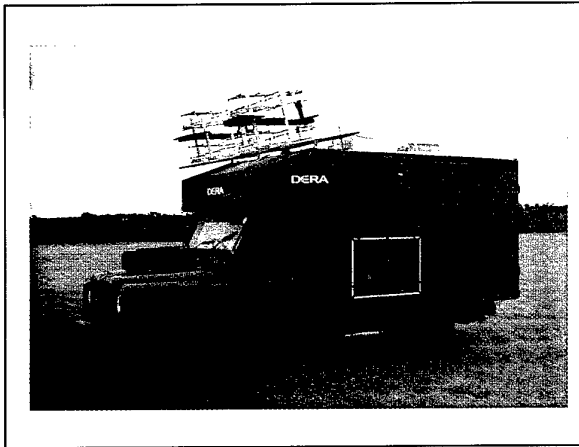


MINDER TRIAL AREA

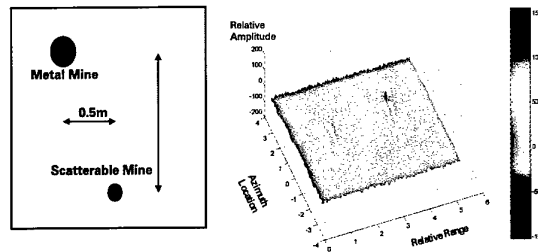


MINDER DISPLAY

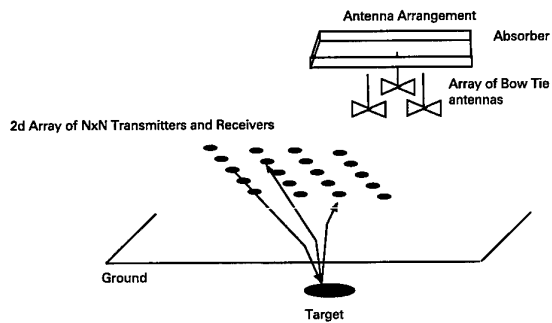




TWO TARGETS ON CONCRETE



FOCUSED PHASED ARRAY CONCEPT



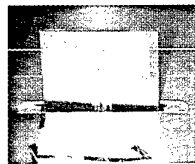
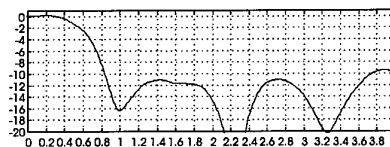
ADVANTAGES OF SYNTHETIC FOCUSED PHASE ARRAY

- High Processing Gain
 - $n(n-1)/2$ where n is the number of Transmit/Receive Locations
- Power Efficient
 - $n/2$ transmissions for one set of voxels
- 3 Dimensional Image
 - Conventional SAR provides only a 2 dimensional image
- Surface clutter is preferentially reduced
 - Bistatic paths share only a small clutter volume common to transmitter and receiver antenna patterns.
- Flexible Processing Possible

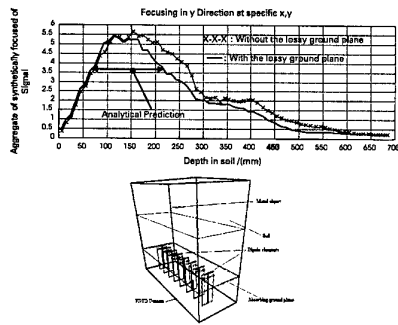
PROGRAMME ACTIVITIES

- Analysis
 - Processing and Data Acquisition Speeds estimated: 30Kph achievable.
 - Physical Models used as basis of Algorithm design.
 - Antenna modelling for non-contact operation.
- Modelling
 - Antenna Array FDTD.
- Experimental Verification and Engineering
 - Laboratory Experiments.
 - Prototype Hardware.

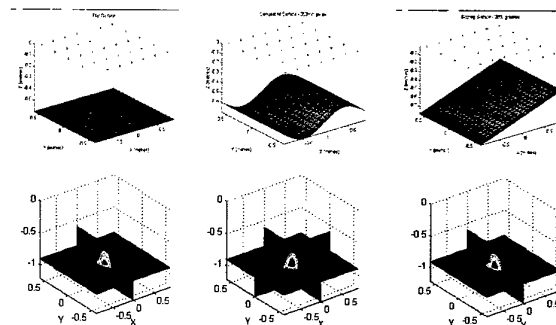
ANTENNA PROTOTYPE



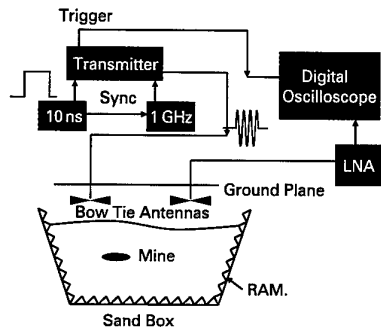
ANTENNA ARRAY DESIGN USING FDTD



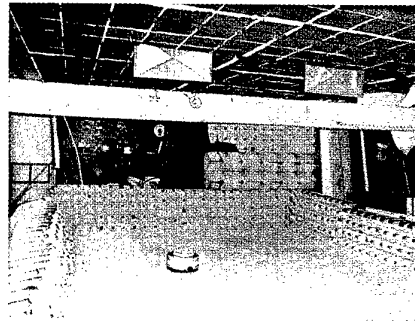
RAY TRACE MODEL



EXPERIMENTAL SETUP



BURIED MINE DETECTION TEST BED



RECEIVED SIGNAL

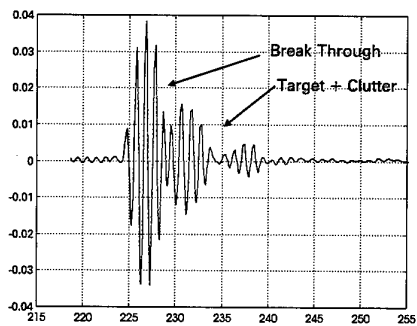
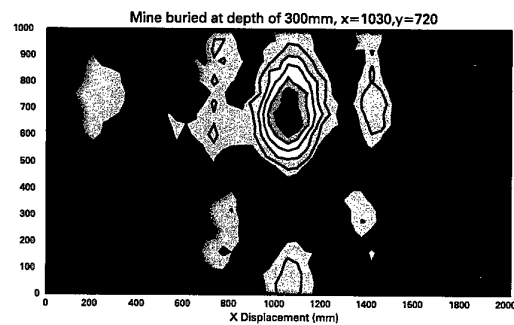


IMAGE OF AP MINE SURROGATE



SUMMARY

- Processing gain observed matches that predicted analytically and by FDTD model.
- Antenna characteristics match FDTD predictions. A bow tie design has been chosen based on these calculations.
- Observed resolution for buried target matches that predicted by analytical theory and verified by FDTD modelling.
- 2d Imaging algorithm verified using an effective 7x5 array by measuring on 595 distinct T/R paths.

THE GERMAN RTD PROGRAMME

Manfred Ott Merk
BMV, D

GE MILITARY PROJECTS ON LAND MINE COUNTERMEASURES

GE PROJECTS ON LAND MINE COUNTERMEASURES

- Mine Field Reconnaissance
 - AAMIS (Airborne Mine Field Detection System)
- CDNOM
 - MMSR (Mobile Mine Detection and Clearing System)
- Mine Field Clearing
 - HAMCS (Heavy Area Mine Clearing System)

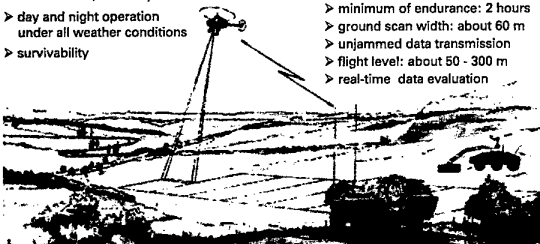
AAMIS

2nd Priority Requirements

- > detection of APM fields at day & good weather conditions
- > detection of mine field borders in short time, accuracy <10 m
- > day and night operation under all weather conditions
- > survivability

1st Priority Requirements

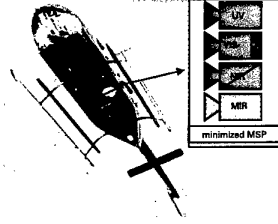
- > detection of ATM fields at day & good weather conditions
- > mine field reconnaissance up to 25 km beyond FLOT
- > minimum of endurance: 2 hours
- > ground scan width: about 60 m
- > unjammed data transmission
- > flight level: about 50 - 300 m
- > real-time data evaluation



AAMIS

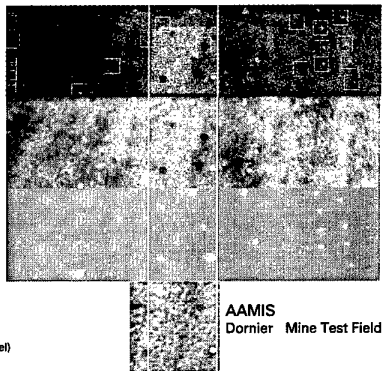
Status May 2000

- initial flight tests with minimised MSP to demonstrate
 - * feasibility of sensor-fusion
 - * on-board data processing performed in 11/98
- false alarm rate unsatisfactory
- improvements of FMC & data processing & merging-software ongoing
- next flight tests planned for July 2000
- real time data generator for simulated helicopter flight under construction, first flight demonstrations scheduled for spring 2001



AAMIS

Dornier Mine Test Field



VIS-Camera

VIS1-Camera (NIR: 0,71 - 0,77 µm)

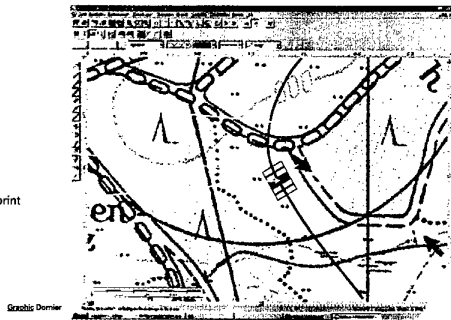
VIS3-Camera (UV: 0,36 - 0,44 µm)

IR-Camera (3 - 5 µm, 256x256 Pixel)

AAMIS

Map Display

- Line of Flight
- Sensor Footprint
- Mine Field

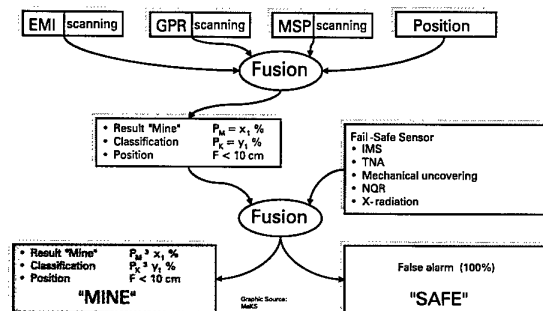


GE PROJECTS ON LAND MINE COUNTERMEASURES

- Mine Field Reconnaissance
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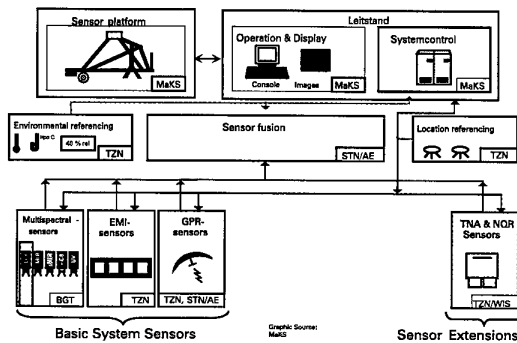
MMSR

Search Strategy with Multisensor System



MMSR

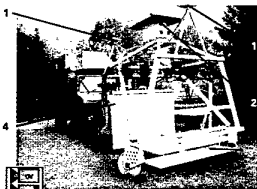
Project Structure



MMSR Mobiles Minensuch- und -räumgerät

Objective

- > detection, localization, classification, identification, marking and neutralization/destruction
- > of surface laid & buried APM & ATM of any type up to 15 to 30 cm depth
- > detection rate > 99%, false alarm rate < 10%



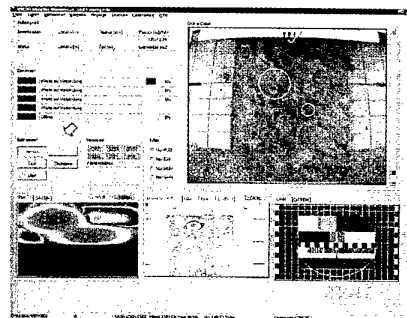
- 1 ORF antenna
- 2 MSP with UV, VIS-RGB, NIR, MIR
- 3 EMI
- 4 GPR antenna

Experimental Vehicle Status October 1999

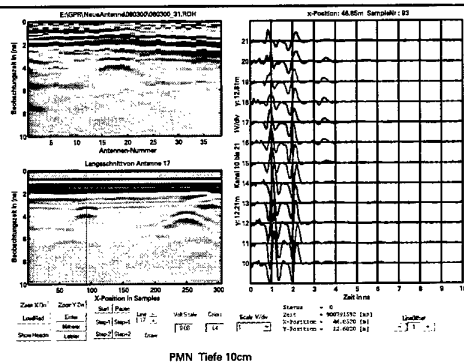
- sensor carrier with metal detector (EMI), multispectral platform (MSP), ground penetrating radar (GPR) and location reference system (ORF) completed, sensors online
- merging-software generated
- false alarm rate of MSP not yet satisfactory
- software optimization ongoing, next presentation 08/2000
- IMS & TNA sensors tested; as verification sensors only conditionally suitable
- NQR-sensor as additional verification sensor under consideration

MMSR

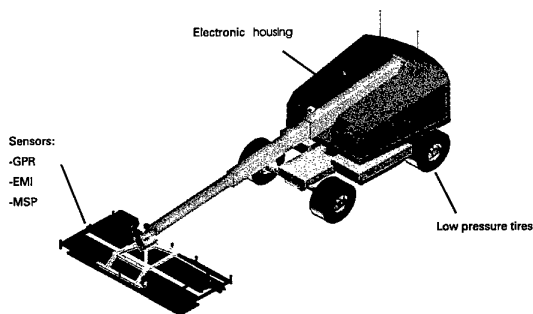
MMI Display



MMSR Ground Penetrating Radar

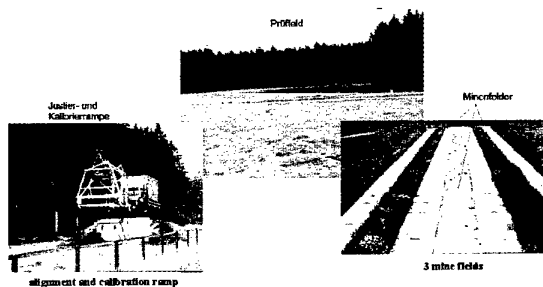


OPERATIONAL SYSTEM (1) CAD-Study of Search Components



MMSR Prüffeld zur Minendetektion

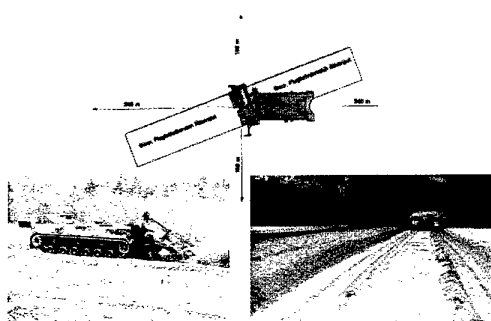
Close-in Detection Test-Range



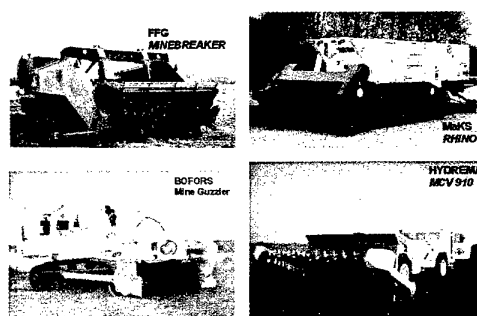
GE PROJECTS ON LAND MINE COUNTERMEASURES

- Mine Field Reconnaissance
 - AAMIS (Airborne Mine Field Detection System)
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 - MMSR (Mobile Mine Detection and Clearing System)
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MCV KEILER

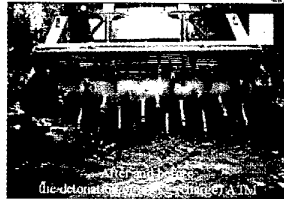
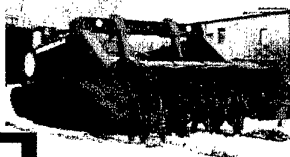


AREA MINE CLEARING EQUIPMENT



MINEBREAKER 2000

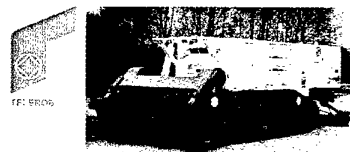
A minefield before ...



... and after the clearance by means of MINEBREAKER 2000.



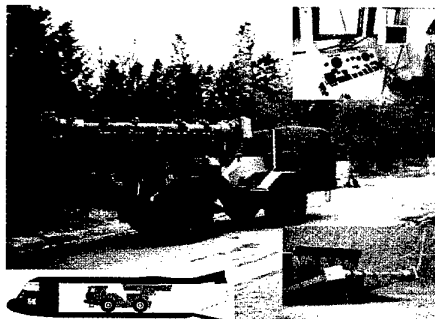
RHINO Mine Clearing System



Technical Data
Overall length: 9.500 mm
Width of tank vehicle: 3.000 mm
Overall height: 3.400 mm
Engine power: 1400 kW
Weight of tank vehicle: 40 t
Top speed: 40 km/h
Max. engine pressure: 120 MPa
Max. speed: 120 km/h
Ground speed: 120 km/h
Clearing depth: 100 mm
Clearing width: 100 mm
Clearing speed: 100 mm/min
Clearing capacity: 100 mm/min
Operating temperature: 0°C to 40°C



HYDREMA MCV 910



HAMCS Heavy Area Mine Clearing System

Operational Requirements

- ↳ safe clearing of AT and AP
- ↳ UXO and fuze parts shall be crushed certain into small pieces, which are ineffective or less hazardous to eliminate or reduce follow-on sweeping
- ↳ protection of operators
- ↳ clearing safety >98% up to 30 cm burying depth
- ↳ operability in climate categories: A1, A2, A3, B1, B2, B3, C0 i.a.w. STANAG 2895
- ↳ in-service date: asap

HAMCS Heavy Area Mine Clearing System

- requesting and compiling technical data, evaluation and selecting - 06/00
- contractual arrangements for equipment rental - 09/00
- preparation for field tests - 09/00
- test runs (1) 10/00 - 11/00
- evaluation 11/00 - 12/00
- test run (2) 02/01 - 03/01
- decision - 03/01
- phase documents, contract 03/01 - 03/02
- procurement 04/02 - 09/03

MAIN ASPECTS FOR EVALUATION OF MINE CLEARING EQUIPMENT

No	Aspect
1	EFFECTIVENESS
2	VULNERABILITY
3	SAFETY OF PERSONNEL
4	FUNCTIONALITY
5	THOROUGHNESS, RELIABILITY
6	MAINTENANCE
7	DOCUMENTATION
8	EDUCATION
9	INFRASTRUCTURE

[1]: NATO SCI-046 CET/CM RSG 2 panel on Landmine Countermeasures, Dr. L.H. Abell, TNO-PML, NL, October 1998

ComScan 450

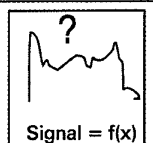
The ultimate solution for detection and identification of mines and UXOs

1. BASIC PROBLEMS OF DEMINING

No. 1: The lack of detection technology

All previous technologies

- Indirect techniques (no direct images of object)
- Ambiguous interpretation of signals
 - > High false alarm rate
 - > Low detection probability



1. BASIC PROBLEMS OF DEMINING

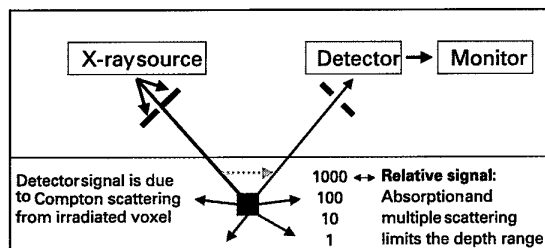
No. 2: High risk to demining personnel

- Lack of remote inspection technology
- Lack of direct imaging technology



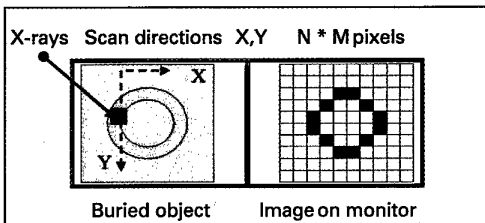
2. X-RAY BACKSCATTER TECHNOLOGY

XBT: The physical principles



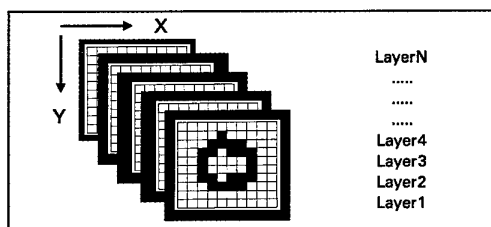
2. X-RAY BACKSCATTER TECHNOLOGY

XBT: The scan procedure with the X-ray pencil beam



2. X-RAY BACKSCATTER TECHNOLOGY

Stored Images: a series of layers



2. X-RAY BACKSCATTER TECHNOLOGY

General advantages of XBT

- DIRECT technique
 - directly interpretable images
- Mapping of material properties (density)
 - structures inside the object are made visible
 - structures around the object are made visible
- Single side access
 - applicable to surface regions

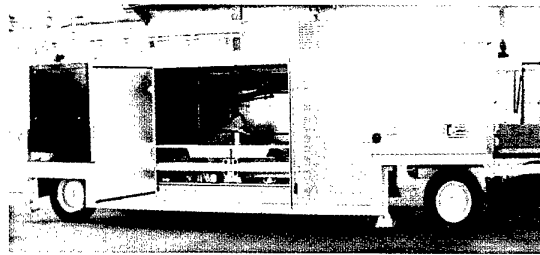
2. X-RAY BACKSCATTER TECHNOLOGY

Benefits of XBT for mine detectionI

- NO direct contact to inspection object
 - *Low risk for equipment*
- Remote operation is feasible
 - *Low risk for personnel*
- Data base :
 - Real image compared to data base image
 - *Fast and correct identification is possible*

3. THE MOBILE SCANNER COMSCAN450

The prototype scanner on the trailer



3. THE MOBILE SCANNER COMSCAN450

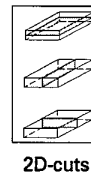
Design and performance

- X-ray source: 450 kV
- Detector: scintillation crystals
- Scan area: max. 1.30 m * 1.20 m
- Scan time: ca 5 min for layer 0.4 m * 0.4 m
- Resolution: variable, typically 10 mm
- Depth range: up to 200 mm

3. THE MOBILE SCANNER COMSCAN450

Image processing and display

- **Image processing:**
 - Layerwise/channelwise corrections (e.g. offset, gain, absorption)
 - Noise reduction, contrast enhancement
- **Image display:**
 - grey colours or heat colours
 - 2D (layers) and 3D- views (volume)
 - video sequences, AVI- files



3. THE MOBILE SCANNER COMSCAN450

Field tests at WTD52 test site



The scanner with army truck

3. THE MOBILE SCANNER COMSCAN450

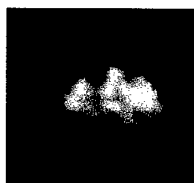
Field tests at WTD52 test site



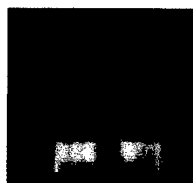
A prepared mine field

4. RESULTS ON MINES FROM FIELD TESTS

2D-views Display possibilities (here: heat colours)



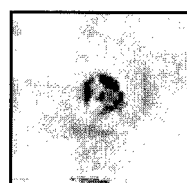
Horizontal layer



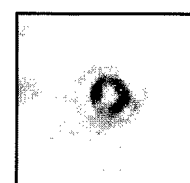
Vertical layer

4. RESULTS ON MINES FROM FIELD TESTS

Example: Tm62 mines buried in humus soil



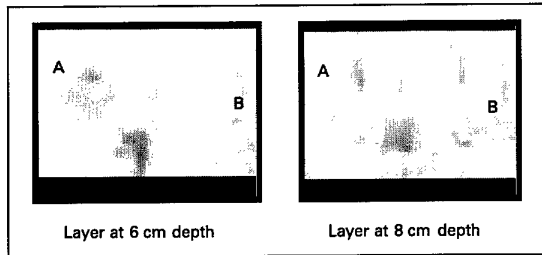
Layer at 6 cm depth



Layer at 10 cm depth

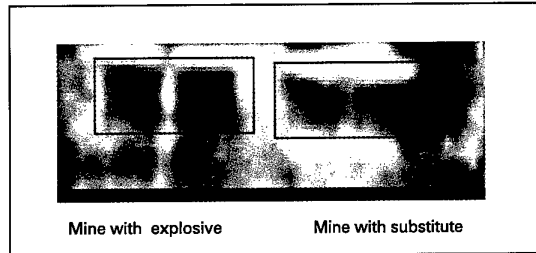
4. RESULTS ON MINES FROM FIELD TESTS

PMN mines filled with: A) substitute; B) explosive



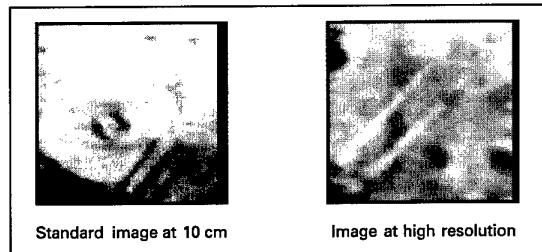
4. RESULTS ON MINES FROM FIELD TESTS

Example: 2D-view (vertical) of PMN mine



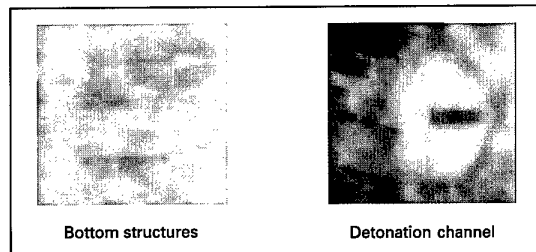
4. RESULTS ON MINES FROM FIELD TESTS

Example: TM62 with pincers on top



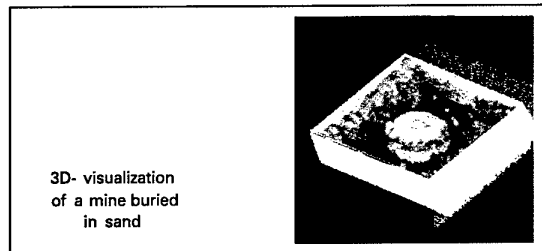
4. RESULTS ON MINES FROM FIELD TESTS

What can be identified?



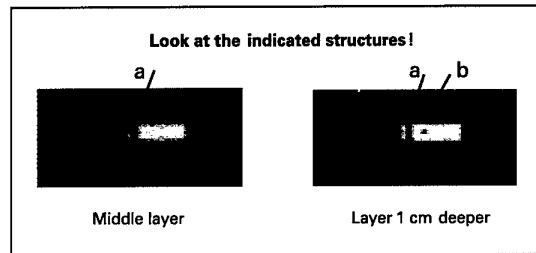
4. RESULTS ON MINES FROM FIELD TESTS

3D-view: A "mineburger"



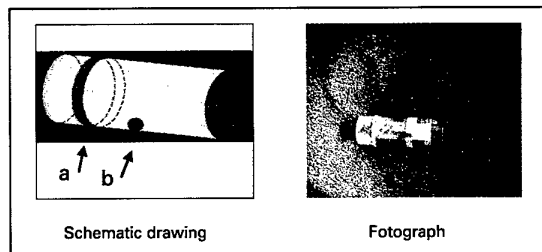
5. RESULTS ON UXOS

2D-view: Guess what it is!



5. RESULTS ON UXOS

The solution: a buried spray can!



6. COMSCAN450: OUTLOOK

What has been achieved?

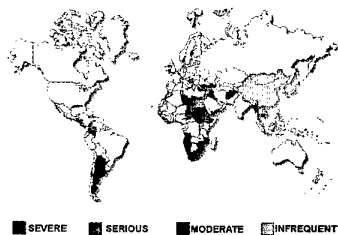
- X-ray backscatter technology (XBT) has been established as the first *direct imaging technique* for buried objects
- XBT shows great opportunities for *detection and identification/ classification* of buried mines and UXOs
- Based on achieved image contrasts a *low false alarm rate* and a *high detection probability* are expected

THE TNO MINE DETECTION APPROACH

Piet Schwering
TNO, NL

OVERVIEW

- Policy and activities of The Netherlands
- Ambition
- Sponsors
- Clusters of projects
- Description of projects
- Expectations of the workshop



POLICY AND ACTIVITIES NETHERLANDS

- Mine Ban Policy: Ratification Ottawa Mine ban Treaty (1999)
- Pool demining instructors (80, 1998-1999): Dutch Armed Forces
- Mine Action Funding (1996-1999): US\$ 40.2 million
- UN Trust Funds: US\$ 14 million
- Victim Assistance: US\$ 1.8 million
- Stockpiling, destruction of 440 000 landmines: US\$ 0.3 million
- Research (1997- 2000): US\$ 11.9 million (Average 20 US\$ million/year)

AMBITION

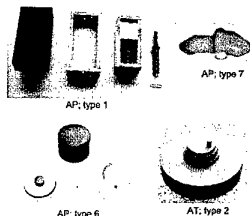
- Ambition for the Netherlands:
The Netherlands will be an international player in humanitarian demining and be a strong pro ban country
- Ambition supported by
 - Ministry of Defence
 - Ministry of Foreign Affairs
 - Minister of Development Co-operation

SPONSORS OF RESEARCH

- Ministry of Defence (Direct project funding)
- Ministry of Defence (Strategic research funding)
- Royal Netherlands Army
- Minister of "Development Co-operation"
- European Union
- International partners
- TNO Corporate funding

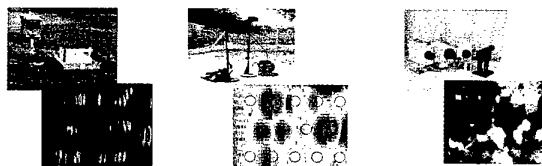
CLUSTERS OF PROJECTS

- 1 Detection techniques for mines
- 2 Detection techniques for explosives
- 3 Signal processing
- 4 Clearance techniques
- 5 Test facilities
- 6 Miscellaneous



Short term versus medium and long term research

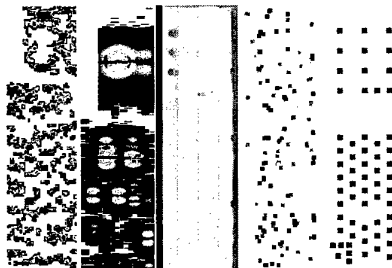
DETECTION TECHNIQUES FOR MINES (1)



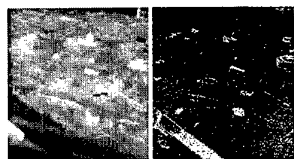
- HOM2000
 - Commercial of the shelf (COTS) sensors GPR, MD, TIR
 - Improved COTS sensors GPR, MD, TIR
 - Anomaly detection (dielectric)
 - Demonstration of sensor fusion

DETECTION TECHNIQUES FOR MINES (2)

- EU projects GEODE, LOTUS
- Sensors GPR, MD, TIR



DETECTION TECHNIQUES FOR MINES (3)



Intensity

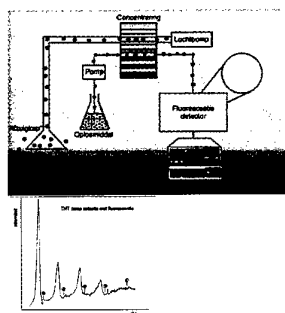


Angle

- EO sensors
 - Active illumination
 - Polarisation (PhD student)
- GPR sensors
 - UWB, Improved processing (PhD student)
- MD sensors
 - IPPTC test of 30 COTS detectors
- Data collection

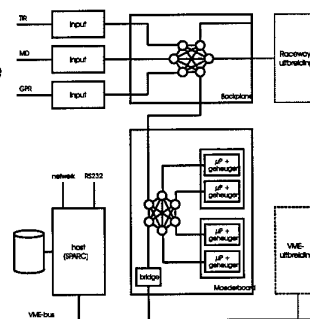
DETECTION TECHNIQUES FOR EXPLOSIVES

- HOM2000 Vapour detection
 - Vapour conc. Levels
 - Vapour detection lev.
- Vapour detection
 - Laser induced fluorescence
 - Electro forese
- Explosive detection
 - NQR
 - TNA



SIGNAL PROCESSING (1)

- HOM2000
- Sensor fusion: Hardware/Software
- Individual sensors



SIGNAL PROCESSING (2)

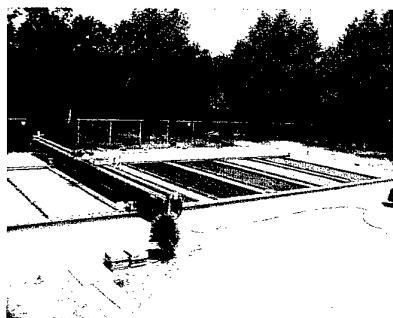
- EO sensors
 - Fusion of polarisation (PhD student)
- GPR sensors
 - Improved processing UWB (PhD student)
- GEODE, LOTUS
 - Sensors GPR, MD, TIR

CLEARANCE TECHNIQUES



- HOM2000
 - Explosive foams
 - Explosively formed projectiles (EFP)
 - Thermite
- Protection
 - Protective shoes
 - "Crash dummies" in vehicles

TEST FACILITIES (1)



TEST FACILITIES (2)

- Test lanes
 - 6 Types of soil
 - Water level controlled
- All metal cleared test platform
 - High accuracy in position and speed
 - No metal components
- Test mines
 - Checked for correct parameters
- Test procedures
- Data collection

TNO POLICY AND AMBITION

Policy

- TNO facilities available for joint research and testing
 - sharing sensors, protocols, testmines and databases
- Independent and objective evaluation

Ambition

- International player in humanitarian demining
 - joint research proposals
 - certified evaluation facility
- EU network of test and evaluation
 - leading role in initiation
 - complementary facilities
 - common standards and protocols

MISCELLANEOUS

- Participation in NATO RTO groups (e.g. dual use)
- Operations research in mine clearance effectiveness

EXPECTATIONS OF THE WORKSHOP

- Maximise the net effect of the national activities in the important field of demining by exchange of information
- Identify a number of topics for successful coöperation in the field of demining
- Narrow tasking of the national R&D organisations to optimise complementarity and minimise duplication

FUTURE KEY ACTIVITIES

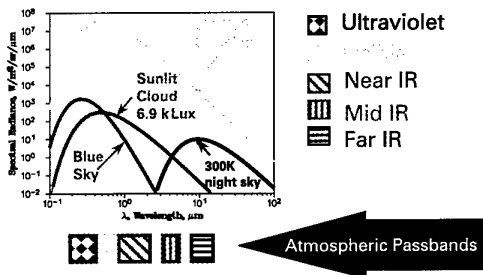
- Sensor Fusion/Signal Processing
- Processing & sensor improvement
 - GPR
 - EO
 - EMI
- Test & evaluation of:
 - Current systems
 - Systems under development
- Centre of technical expertise

SESSION:
Advanced Sensors Systems

POLARIMETRIC HYPERSPECTRAL IMAGING

Charles Di Marzio
Northeastern University

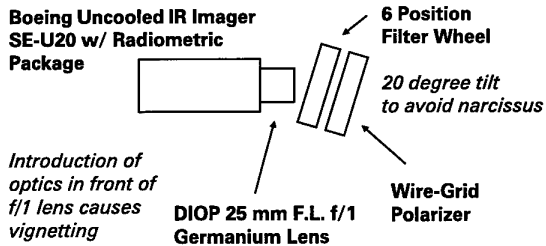
TYPICAL NATURAL RADIANCE LEVELS



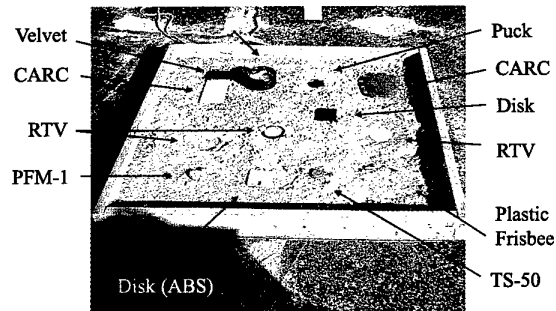
PASSIVE IR DETECTION AND DISCRIMINATION OF MINES

- EXPLOIT ALL AVAILABLE ATTRIBUTES:
 - SPATIAL
 - SPECTRAL
 - POLARIZATION

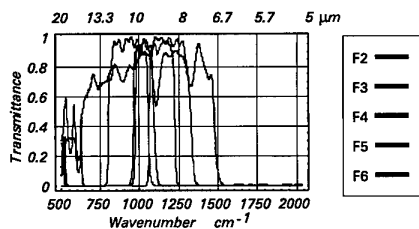
IMAGER CONFIGURATION



CLOSEUP OF "MINEFIELD"



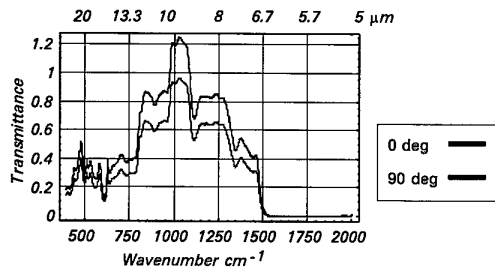
FILTER RESPONSE CURVES



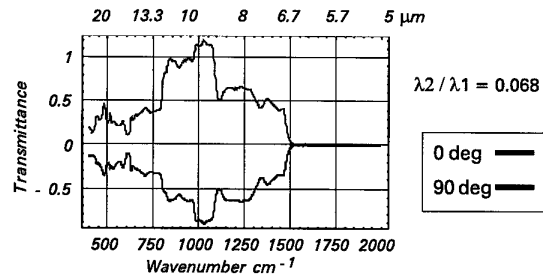
Principal Components Analysis

- 12 Images: 6 Filters X 2 Polarizer Angles
- Perform Principal Components Transformation (Eigenvector Decomposition)
- Generate images in eigenvector space
 - RGB image using 3 of 12 eigenvectors
 - Grayscale image using single eigenvector

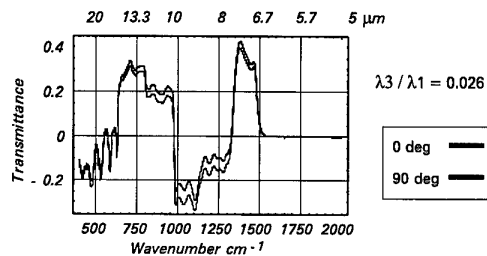
EIGENVECTOR #1 (TEMP.)



EIGENVECTOR #2 (POLARIZATION)



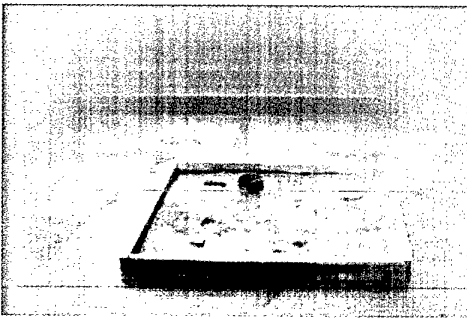
EIGENVECTOR #3 (COLOR)



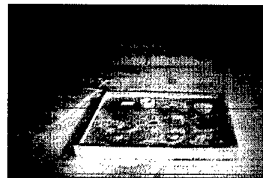
PHYSICAL SIGNIFICANCE OF PCA

- Inspection of the eigenvectors reveals an apparent *physical significance*:
- E1 - Temperature (Wideband intensity)
- E2 - Polarization (Wideband)
- E3 - Color
- E4 - Color and Polarization
- E5 - Polarization (small I)
- E6 - Polarization (small I)

PCA Image (E2, E3, E4)



2 - 6 μM IMAGE



- Filter #6 image subtracted from image with no filter.
- Compared to 8-14 μm:
 - More Solar
 - Less Thermal
- Illumination from back right
- Strong Shadows

CONCLUSIONS

- A clear understanding that a polarimeter geared toward mine detection requires a spatial scale consistent with the mine dimensions and respective of spatial scale of primary clutter sources
 - The most difficult clutter sources to date are man made
 - Will investigate angle of polarization as an attribute to suppress clutter
- Hyperspectral polarimetry offers essential capabilities over broad band polarimetry in applications such as demining where small targets occupy one IFOV or less (subpixel) and require spectral discrimination

CONCLUSIONS (CONT'D)

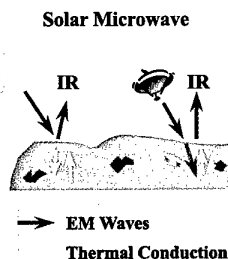
- Imaging polarimeter demonstrated strong performance by the microbolometer FPA in the polarimeter mode
 - Robust results with cloud cover
 - Encouraging results in multispectral mode (6 bands)
- Laboratory measurements or other knowledge of the spectral reflectance properties of the targets in each application are necessary to support Hyperspectral Polarimetry
- Variable spatial and spectral resolution are important features to build into any polarimeter intended for a broad set of applications

STIMULATED THERMAL DETECTION

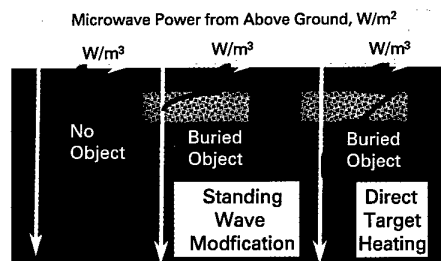
Charles Di Marzio
Northeastern University

MOTIVATION FOR MICROWAVE ENHANCEMENT

- **Solar Ground Heating**
 - 1000 W/m² Sufficient
 - Dawn/Dusk Required
 - Minimal Penetration
- **Microwave Heating**
 - Comparable Power
 - No Sunny Day, Dawn/Dusk Constraint
 - Variable Penetration



MULTIPLE MECHANISMS FOR MEIT CONTRAST

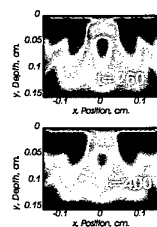
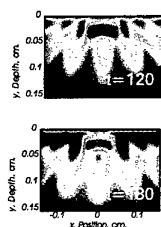


MEIT THEORETICAL ANALYSIS

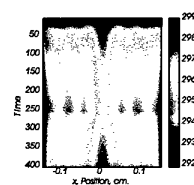
- 2D model of electromagnetic energy distribution
 - Different Sources
 - Frequencies, Incident Angles, Polarizations
 - Different Soils
 - Surface Roughness, Composition
 - Different Mines
 - Locations, Materials
- 2D model of thermal diffusion
 - Diffusion Equation
 - Absorbed Microwave Power Density as Source
 - Convection at Surface

SAMPLE RESULTS FROM THERMAL MODEL

Sample Temperature Distributions
Heating: $0 < t < 250$

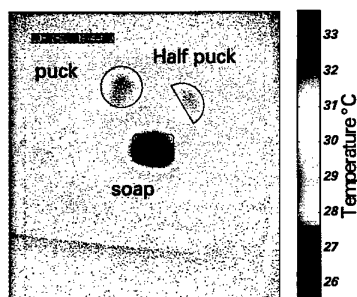


Time History of Surface Temperature



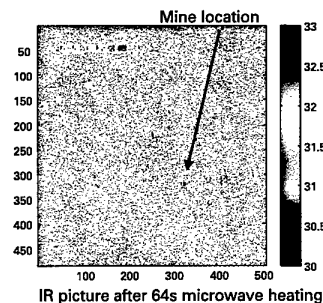
IMAGES AFTER HEATING PROVIDE SHAPE

- Targets:
 - a bar of soap and two pucks
- Depth:
 - 1cm
- Background:
 - dry sand

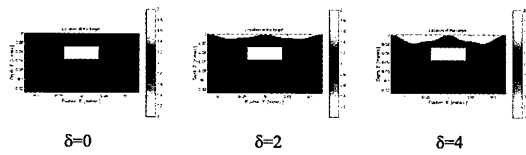


EXPERIMENT RESULTS 2:57PM, JUNE 29, 01999

- Three mines were buried, only one was in the heating area.
- The blades of grass were heated up by microwave energy.
- The environmental temperature was decreasing slightly



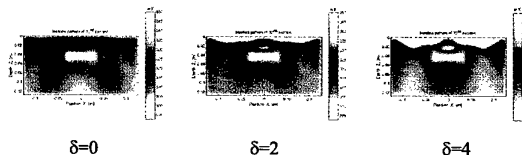
SURFACE TYPES & TARGET LOCATIONS



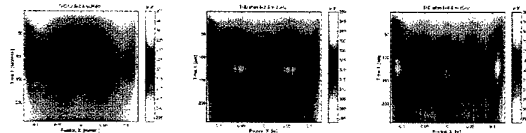
Roughness(δ) INCREASES

- Microwave power source: 400 Watts (in simulation)
- Soil relative dielectric constant: $6.5 + j0.18$
- Soil conductivity: $0.075/\text{m}$
- δ = Ripple factor of the sinusoidal surface, determines the amount of roughness.
- Target relative dielectric constant: 2.9
- Target conductivity: $0.0015/\text{m}$
- Target size: $7.5\text{cm} \times 2.5\text{cm}$
- Target depth: 3cm.
- Frequency of operation: 2GHz

TEMPERATURE DISTRIBUTION DURING HEATING



TIME HISTORIES FOR DIFFERENT SURFACE ROUGHNESS SCALES

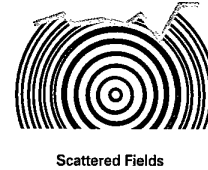
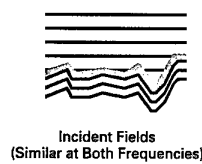


Roughness(δ)

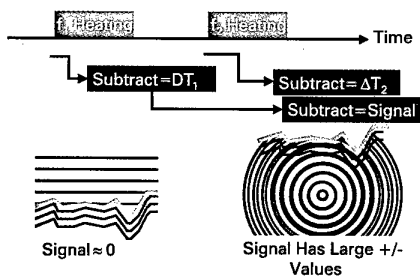
- As roughness increases, we LOSE the target information.
- Simulations were performed at 2GHz.

TWO-FREQUENCY HEATING

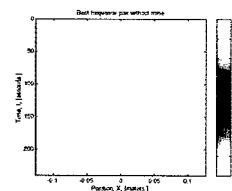
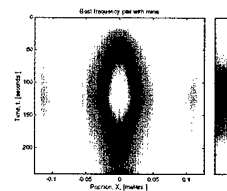
- Surface Effects Similar at Both Frequencies
- Propagation Effects Different



PROCESSING 2-FREQUENCY IMAGES



DUAL-FREQUENCY RESULTS: THE BEST PAIR (1.75GHZ. - 0.9GHZ.)



CONCLUSIONS AND FUTURE PLANS

- Dual frequency finds the mines under rough surfaces.
- Some frequency pairs are better than others.
- We will carry out a series of experiments with 915 MHz-2.45 GHz pair, and is readily available.
- This frequency pair is not the best but it gives results close to the perfect case.
- We will explore the random surface effects on the detection of mines.

THE POTENTIAL OF POLARIMETRIC TIR AND ITS STATE OF DEVELOPMENT

Gareth. D. Lewis^{1,2}, David. L. Jordan³

¹EU Joint Research Centre SAI/TDP, Via E. Fermi, Ispra (VA), Italy

²Gareth is on sabbatical leave from 3

³Optical Control Technologies Group, DERA Malvern, UK, E-mail: gareth.lewis@jrc.it,
tel: +39 0332 786444, fax 785772

Scene clutter problems rather than more fundamental signal-to-noise considerations, often limit the detection of man-made objects (e.g. landmines) by passive Electro-Optical (EO) sensors. One method of reducing scene clutter is to exploit the polarimetric content of an image, information which is often ignored, to discriminate man-made objects in this case landmines, from the natural background. Man-made objects tend to consist of a series of regular facets that can give rise to significant polarimetric signatures. The level of polarization depends on a number of factors of which sensor waveband, viewing angle, material dielectric constant, surface texture and environmental conditions are important. An important consideration for mine detection is that plastic, painted as well as metallic mines exhibit significant levels of polarization and can therefore be detected. The figure below shows an example of how polarimetric infrared imaging (8-12 microns) can be used to detect plastic anti-personnel (AP) mines in a cluttered scene (mixture of grass and gravel).

The usefulness of this technique depends on a sufficient polarimetric contrast between the object (landmine) and the natural background. In the 3-5 microns and 8-12 microns infrared wavebands the background generally does not exhibit significant polarization levels. Whilst in the visible waveband (0.4-0.7microns) the background polarimetric signature varies with weather conditions, from being significantly polarized in clear sunny conditions to little polarimetric signature during overcast skies. In the latter weather condition, sufficient polarimetric contrast is often present for object detection.

Polarimetric techniques are complimentary to standard EO systems, particularly when operated in highly cluttered backgrounds. They offer a method of reducing search areas so that more sensitive, narrow field of view sensors can be deployed.



Standard IR (3 AP mines at 15m)



Polarimetric IR (same scene)

Advantages	Limitations
<ul style="list-style-type: none">• Detection: in cluttered backgrounds• Detection in zero thermal contrast scenes• Detection of plastic and minimum metal mines• Low-cost upgrade to existing EO sensors• Determination of object shape• Simple processing requirements	<ul style="list-style-type: none">• No buried mine detection• Requires line-of-sight to the mine• Some polarimetric systems require a minimum number of image frames to process the polarimetric data.• Reduces system signal-to-noise ratio• Narcissus problems caused by reflections from the polarizer.

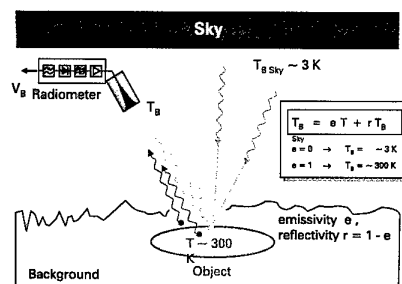
RECENT ADVANCES IN THE DETECTION AND IDENTIFICATION OF LANDMINES BY MW RADIOMETRY

Markus Peichl
DLR, D

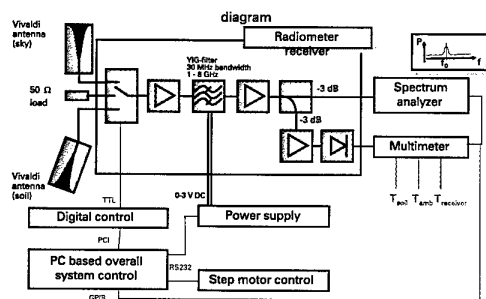
STRUCTURE OF THE PRESENTATION

- Phenomenology of radiometric measurement techniques
- Experimental setup for spectral near field imaging
- Experimental results
- Conclusions

PHENOMENOLOGY OF RADIOMETRIC OBSERVATIONS



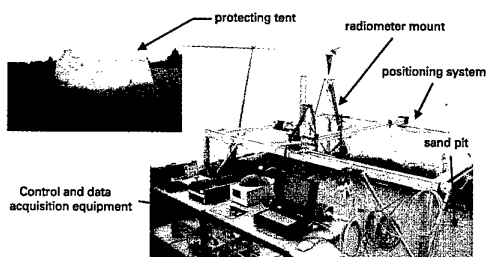
DLR MINE DETECTION RADIOMETER SYSTEM (HOPE PROTOTYPE) - BLOCK



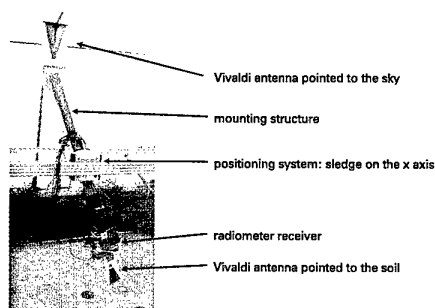
DLR MINE DETECTION RADIOMETER SYSTEM (HOPE PROTOTYPE) - TECHNICAL DATA

- Sensor type: Broadband multi-spectral microwave radiometer.
- Operation: Two-dimensional near-field brightness temperature measurement using frequency sweep.
- Center frequencies: 1.7 - 7.0GHz, continuously adjustable.
- Bandwidth: 30...200MHz, depending on BP filter.
- Temperature resolution: < 1.5K at 10ms integration time.
- Antenna: Vivaldi antenna in microstrip technology.
- 3dB width: 50...100°, depending on frequency and plane section.
- Calibration: Internal using a 50 Wload and a sky antenna.
- Data acquisition/control: Laptop having A/D conversion and digital I/O.

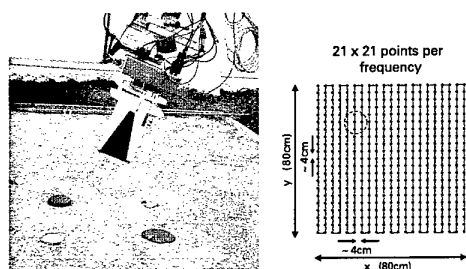
DLR MINE DETECTION EXPERIMENTAL SETUP



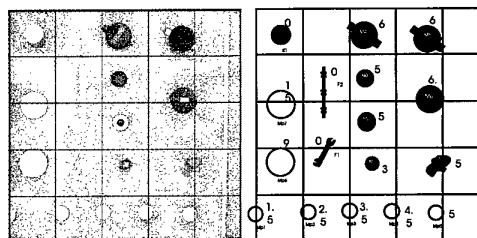
RADIOMETER MOUNT



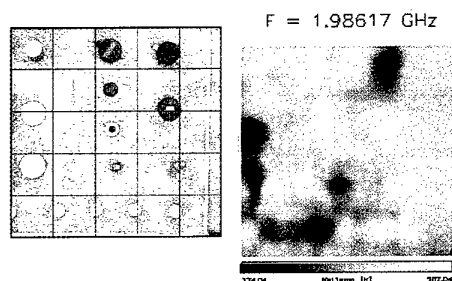
SCANNING GEOMETRY



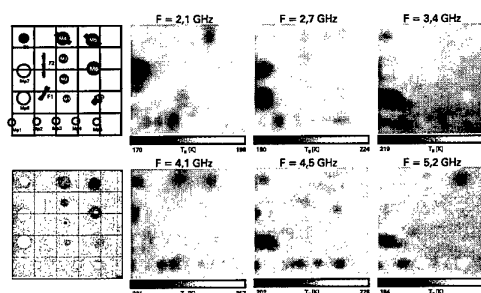
PHOTOGRAPH AND SKETCH OF A BURIED-OBJECTS SCENARIO



RADIOMETRIC MEASUREMENT RESULTS OF THE BURIED-OBJECTS SCENARIO



SELECTED RADIO-METRIC MEASUREMENT RESULTS OF THE BURIED-OBJECTS SCENARIO



CONCLUSIONS

- Main results:**
- Promising radiometric signatures of on- and sub-surface mines were detected (sand layer: ~ 5-10cm, contrast range: ~10-20K).
 - A temperature resolution of ~ 1K is sufficient.
 - The actual spatial resolution is sufficient (near field mode).
 - The measurements are independent of sky conditions.
 - The signatures appear very different for different frequencies.

- Identified problems:**
- A detailed understanding of the electromagnetic interaction of mine, soil conditions and frequency is required.
 - „Artificial noise sources“ have to be suppressed efficiently.
 - external: eg. broadcasting, TV, GPS, radar, aggregates.

- Future work:**
- Improvement of the experimental system (receiver concept).
 - Internal: eg. system stability, self interferences.
 - Data collection (comparison to theoretical results).
 - Receiver integration and test (MW, IF, LF circuits, digital control), HOPE system integration and test.

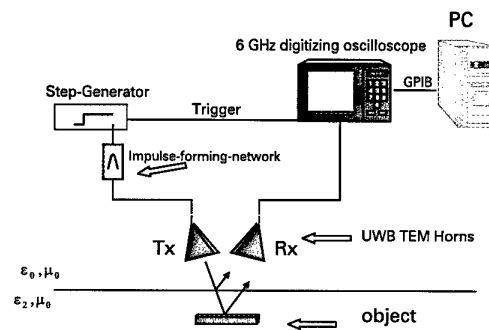
DESIGN OF AN IMPULSE UWB GPR SYSTEM AND ASSOCIATED SIGNAL PROCESSING

Bart Scheers
RMA, B

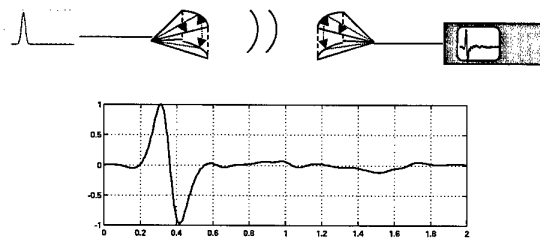
CONTENT

- Description of the UWB GPR
- Time domain model of the UWB GPR
 - Antennas as convolution operator
 - Radar range equation in the time domain
 - Range performance of the system
- Migration by Space-Time Deconvolution
- Results & conclusions

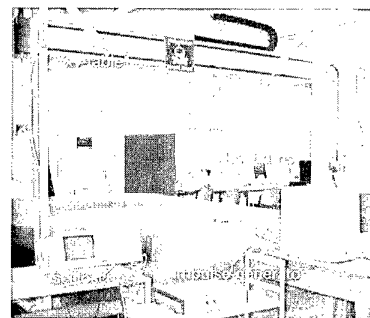
DESCRIPTION OF THE UWB GPR



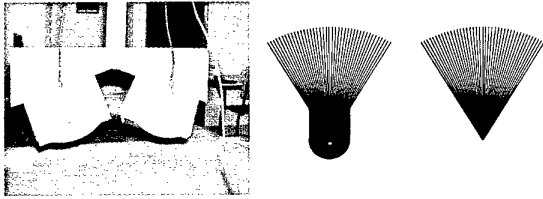
DESCRIPTION OF THE UWB GPR



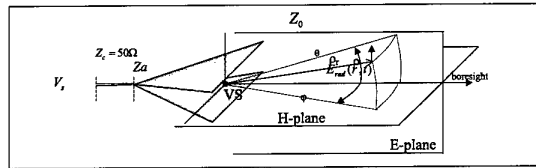
DESCRIPTION OF THE UWB GPR



TEM HORN ANTENNAS



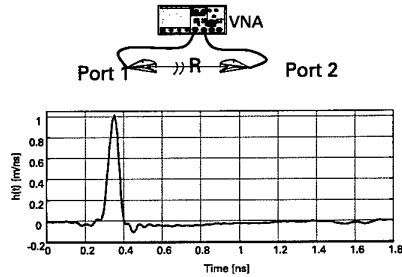
ANTENNAS AS CONVOLUTION OPERATORS



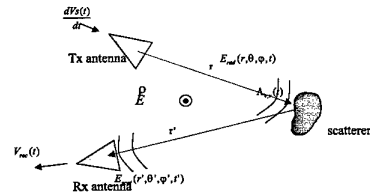
$$E_{rad}(\hat{p}, t) = \frac{1}{2\pi r c} h_{N,Rx}(\theta, \varphi, t) \otimes \frac{\sqrt{Z_0}}{\sqrt{Z_c}} \frac{dV_s(t-t_d)}{dt}$$

$$V_{rec}(t) = \frac{\sqrt{Z_c}}{\sqrt{Z_0}} h_{N,Rx}(\theta, \varphi, t) \otimes E_{inc}(t)$$

ANTENNAS AS CONVOLUTION OPERATORS

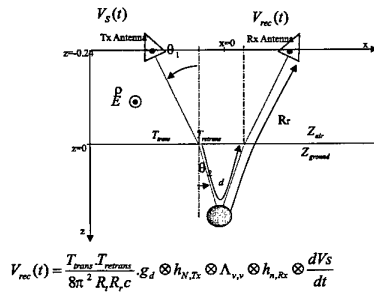


TIME-DOMAIN MODEL OF THE UWB-GPR



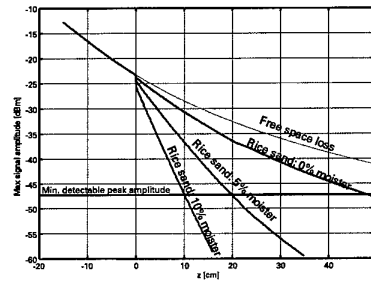
$$E_{scat}(r', \theta', \varphi', t') = \frac{1}{4\pi r'} \Lambda_{v,v}(\hat{p}, \hat{p}') \otimes E_{rad}(r, \theta, \varphi, t)$$

TIME-DOMAIN MODEL OF THE UWB-GPR

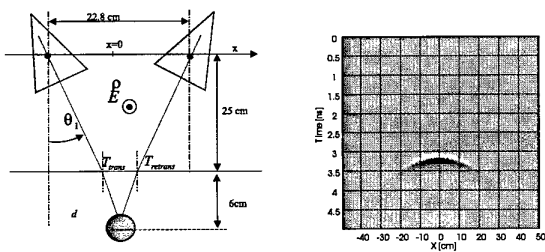


$$V_{rec}(t) = \frac{T_{trans} T_{rec}}{8\pi^2 R_t R_r c} g_d \otimes h_{N,Tx} \otimes \Lambda_{v,v} \otimes h_{N,Rx} \frac{dV_s}{dt}$$

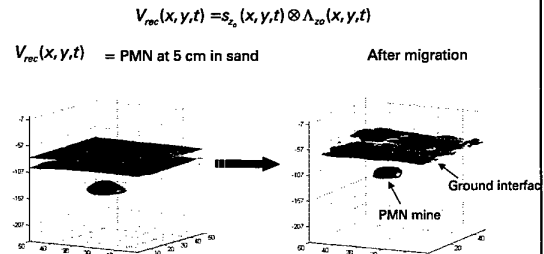
RANGE PERFORMANCE for metallic sphere (5cm radius) in sandy soil



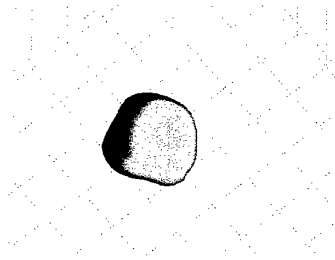
POINT-SPREAD FUNCTION



MIGRATION BY SPACE-TIME DECONVOLUTION

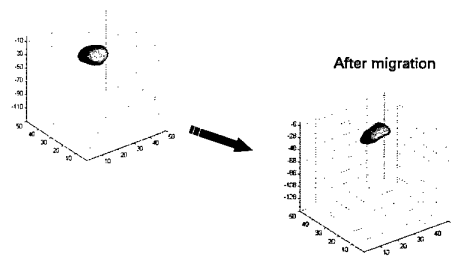


RESULTS



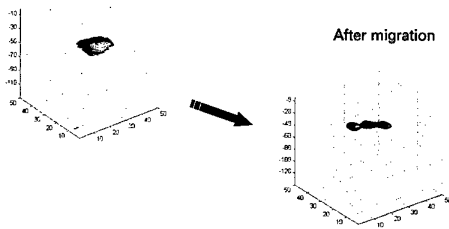
RESULTS

Brick (15*9*6cm) at 5 cm in sand



RESULTS

barbed wire (20cm) at 5 cm in sand



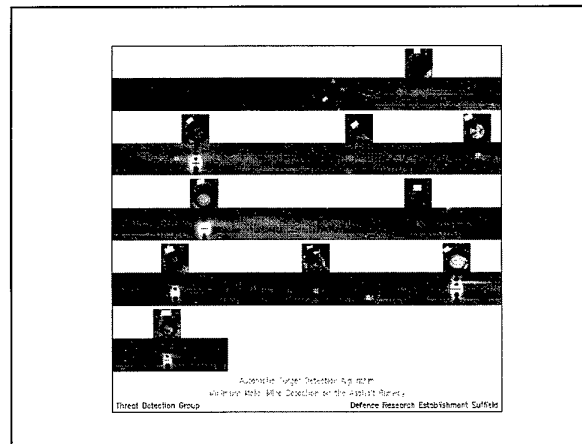
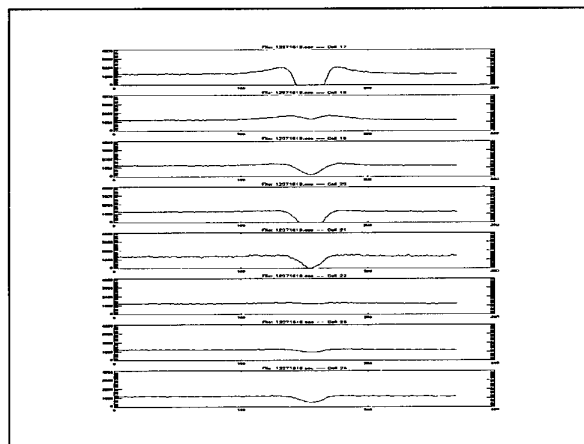
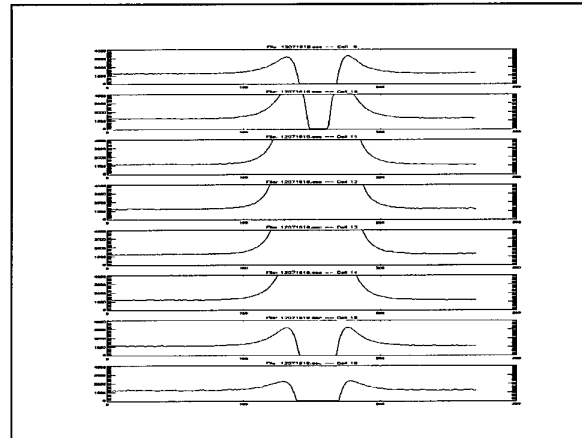
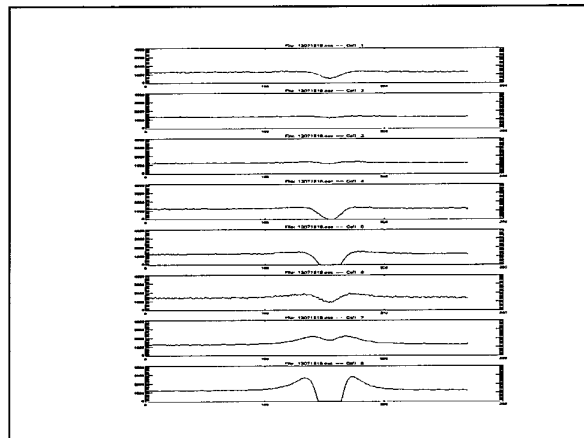
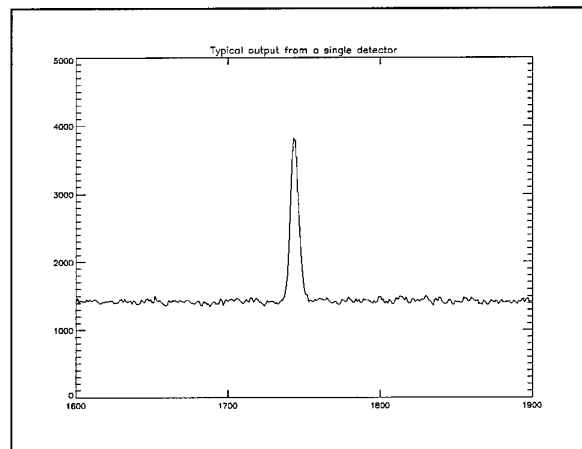
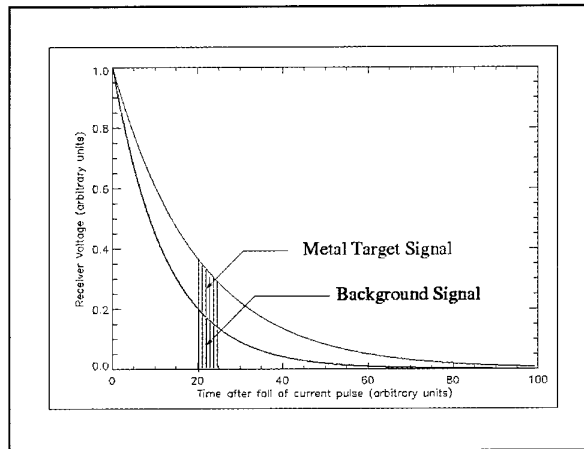
CONCLUSION

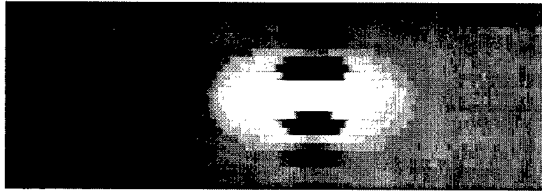
- Accurate time-domain model can be found by considering the system as a cascade of linear responses
- Normalized impulse response = good and powerful description of antennas
- Time-domain model has a lot of useful applications
- Range performance as a function of min detectable peak amplitude \Rightarrow strong attenuation when moisture \uparrow
- Migration by space-time deconvolution

- ⊗ : capable of detecting small and shallow laid objects
- ⊗ : UWB GPR has potential to discriminate buried objects by their 3D shape
- ⊗ : limited range performance in wet soil

INTERPRETATION OF SIGNALS FROM ARRAYS OF ELECTROMAGNETIC INDUCTION DETECTORS

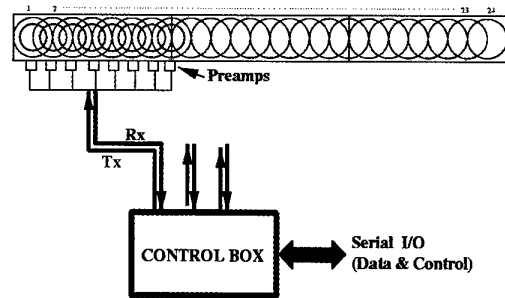
Yoga Das
CCMAT, Canada



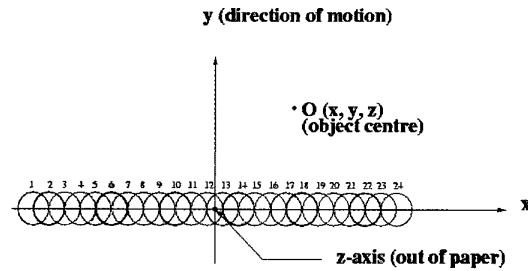


- 24 AN19/2 sensor heads
- 3 meter detection swath
- can operate on the ground
- 12 bit data at 30Hz

• produces an "image"



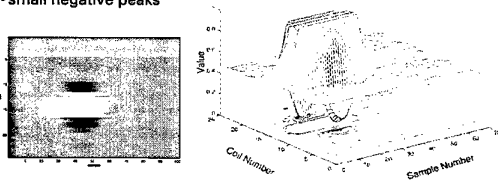
Minimum-Metal Mine Detector Array



$$V_{\text{coil}} = G[H_{\text{tot}}^T \cdot H_{\text{coil}}^R]$$

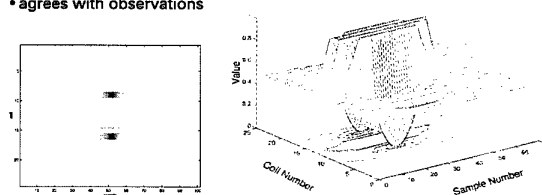
RESPONSE OF A LARGE TARGET

- large positive peak
- small negative peaks



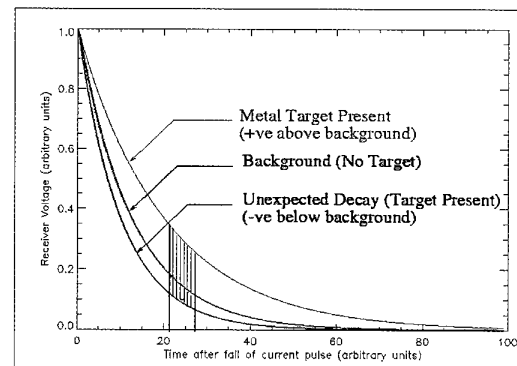
MODELED RESPONSE OF A LARGE TARGET

- extended single coil model
- agrees with observations



MANY RESEARCH OPPORTUNITIES

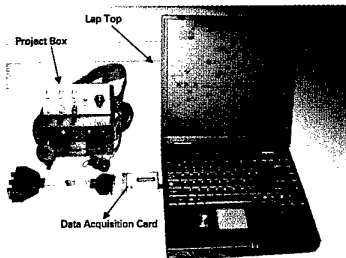
- ATD Algorithms
- Multiple Targets
- Target Resolution
- Imaging Possibilities
- Other Arrays



EMI DETECTION

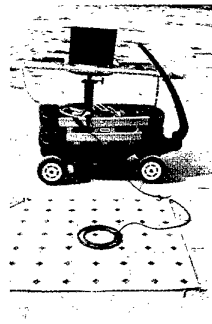
Lloyd Riggs
Auburn University

INSTRUMENTATION DEVELOPED TO ACQUIRE "RAW" TIME-DOMAIN WAVEFORMS FROM THE AN/PSS-12



The project box consists of the AN/PSS-12 signal processing unit with an amplifier attached to the top. The time-domain voltage waveforms acquired from the project box, via the data acquisition card, are stored on the laptop for subsequent processing.

MOBILE TEST PLATFORM USED TO COLLECT DATA FROM THE JUXOCO TEST SITE



The plastic wagon carried the laptop computer, data acquisition card, project box, and all power sources.

A linoleum sheet, 1m x 1m in dimension, with an x-y coordinate system drawn in the center was placed over each of the test squares in the JUXOCO Test site. Time domain response data was collected at a number of positions on the x-y grid for each buried object.

SIGNAL PROCESSING ALGORITHMS

We have developed two different signal processing algorithms to discriminate among blanks, metallic mines and metallic clutter.

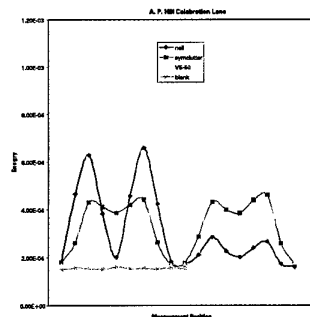
1) Symmetry Detector

- Energy of measured voltage signal is calculated at specific points along two orthogonal axes.
- Symmetry (or lack thereof) is determined by comparing spatial energy signatures measured along the two orthogonal axes
- Generally, metallic mines have symmetrical spatial energy signatures whereas metallic clutter tends to have asymmetrical signatures.

2) Decay Rate Detector

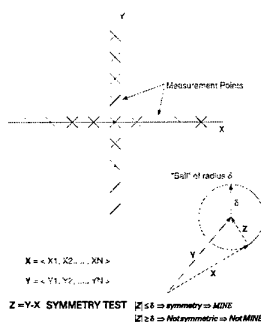
- A single voltage-versus-time signal is measured directly over the center of the buried object.
- An object's voltage-versus-time signal is in the form of a simple exponentially decaying waveform. The rate of exponential decay depends on the object's geometry and electrical constitutive parameters.
- Ideally, the set of exponential decay rates associated with mines is distinct from the set of exponential decay rates associated with metallic clutter.

EXAMPLES OF SYMMETRY MEASUREMENTS



This plot shows the spatial energy measurements of four objects. The symmetric yellow curve is the spatial energy of a VS-50 mine. The asymmetric dark blue curve is the spatial energy of a nail. Most mines have symmetrical spatial energy curves while most clutter items have asymmetrical energy curves.

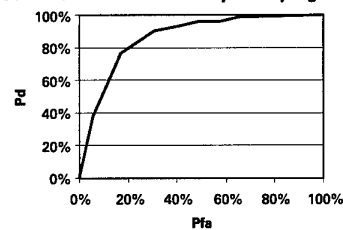
QUANTIFYING SYMMETRY



A vector, X , is formed from the abscissa energy measurements. A vector, Y , is formed from the ordinate energy measurements. An error vector, Z , is formed by subtracting corresponding points of the ordinate and abscissa vectors. An error threshold, δ , is set. If the error is below the threshold, the object is qualified as symmetrical, if above the threshold, the object is qualified as asymmetrical.

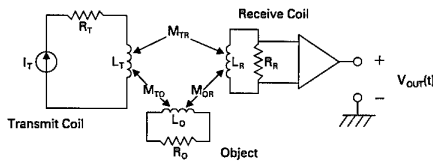
SYMMETRY ALGORITHM PERFORMANCE

PSS-12 Performance Results Symmetry Algorithm



- The ROC curve above is formed by calculating the probability of detection versus probability of false alarm for the items in the blind test grid as a function of the magnitude of the error, δ .
- This is a very simple algorithm that produces a ROC well above the chance diagonal!

METAL DETECTOR - OBJECT INTERACTIONS MODELED AS MAGNETICALLY COUPLED CIRCUIT

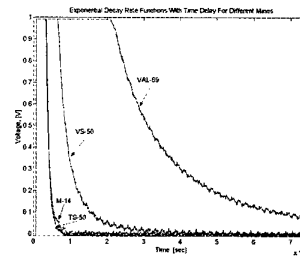


$$V_{out}(t) = Ae^{-\gamma t} + Be^{-\delta t}$$

Design Considerations: (Ideally One Desires)

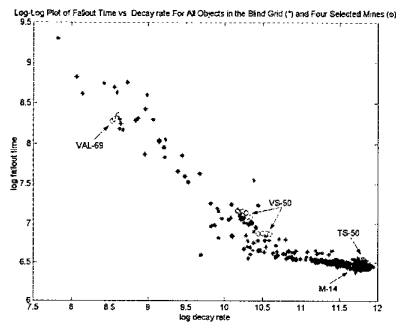
- $S_R \gg S_O$ (fast receive coil decay rate)
- $B/A > 1$ (strong object coupling)

EXPONENTIAL DECAY RATE AND SATURATION FALLOUT COMPARISON FOR FOUR DIFFERENT LANDMINES



- The four mines shown have four different decay rates and coupling strengths.
- The coupling strength of the buried object manifests itself as the time where the signal falls out of amplifier saturation.

LOG-LOG PLOT OF ALL OBJECTS IN THE BLIND GRID AND FOUR SELECTED MINES IN THE TWO-DIMENSIONAL FEATURE SPACE (Saturation Duration versus Decay Rate)



DECAY RATE AND FALLOUT TIME LIKELIHOOD RATIO TEST

$$H_0 \text{ "clutter": } r(t) = e^{-\frac{t-\tau_c}{\tau_c}} + n(t) \quad H_1 \text{ "mine": } r(t) = e^{-\frac{t-\tau_m}{\tau_m}} + n(t)$$

S - decay rate of object
 τ - duration of saturation subscript c - Clutter Object subscript m - Mine

Bayesian Probability Theory Leads to a Likelihood Ratio Test

Probability Measurement was
Derived from a Mine Signature

$$P(r | \tau_m, \tau_c, H_1) = (2\pi)^{-\frac{N}{2}} \sigma^{-N} \exp \left[-\frac{1}{2\sigma^2} \left(\frac{r(t) - e^{-\frac{t-\tau_m}{\tau_m}}}{\sigma} \right)^2 \right]$$

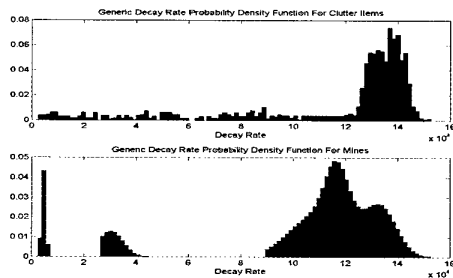
Probability Measurement was
Derived from a Clutter Signature

$$P(r | \tau_c, \tau_m, H_0) = (2\pi)^{-\frac{N}{2}} \sigma^{-N} \exp \left[-\frac{1}{2\sigma^2} \left(\frac{r(t) - e^{-\frac{t-\tau_c}{\tau_c}}}{\sigma} \right)^2 \right]$$

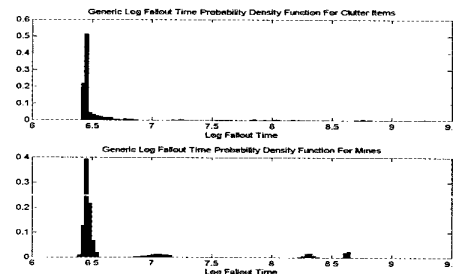
Likelihood Ratio Test

$$\Lambda(r) = \frac{\prod_{i=1}^N \exp \left[-\frac{r(t_i) - e^{-\frac{t_i-\tau_m}{\tau_m}}}{2\sigma^2} \right] \cdot P_{\tau_m}(\tau_m) \cdot P_{\tau_c}(\tau_c)}{\prod_{i=1}^N \exp \left[-\frac{r(t_i) - e^{-\frac{t_i-\tau_c}{\tau_c}}}{2\sigma^2} \right] \cdot P_{\tau_c}(\tau_c) \cdot P_{\tau_m}(\tau_m)} \stackrel{H_1}{\geq} \gamma$$

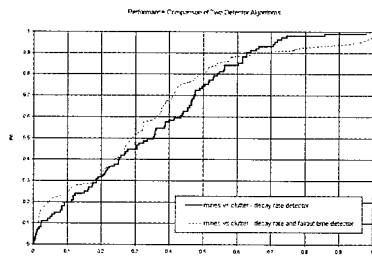
DISTRIBUTIONS FOR DECAY RATES AND SATURATION DURATION FOR MINES AND CLUTTER OBJECTS IN BLIND TEST GRID



DISTRIBUTIONS FOR DECAY RATES AND SATURATION DURATION FOR MINES AND CLUTTER OBJECTS IN BLIND TEST GRID



ROC SHOWING PERFORMANCE OF DECAY RATE ALGORITHM ON BLIND GRID



- The ROC curve above is formed by calculating the probability of detection versus probability of false alarm for the items in the blind test grid as a function of the likelihood-ratio threshold, γ .
- This is an algorithm that produces a ROC above the chance diagonal.

SIGNAL PROCESSING TOOLS (IMAGING AND SIGNATURE MODES) FOR STANDARD METAL DETECTORS

Pascal Druyts
RMA, B

OVERVIEW

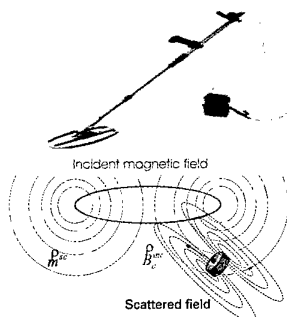
- Introduction
- Metal detector principle
- Target models
- Imaging
- Magnetic polarizability tensor
- Temporal signal
- Conclusion

INTRODUCTION

- Humanitarian demining performed mainly with a metal detector (MD)
- MD
 - Very sensitive (Pd=100% ... max depth 10cm, etc.)
 - Detects any metal scrap (barbed wire, bullet casing, etc.) => FAR very high
- To reduce FAR, add target identification/classification capability:
 - Other sensors (fusion, etc.)
 - Advanced processing of MD output

MD PRINCIPLE

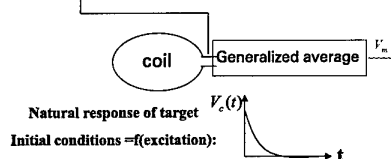
- MD Generates a time varying magnetic field (pulsed or CW).
- Eddy currents are induced in conductive bodies
- Backscattered field is sensed by the detector



ADVANCED PROCESSING OF MD OUTPUT

$$V_c(s) = \alpha(s) \hat{H}_{c0}^T(\hat{P}_i) \hat{M}_i(s) \hat{H}_{c0}(\hat{P}_i)$$

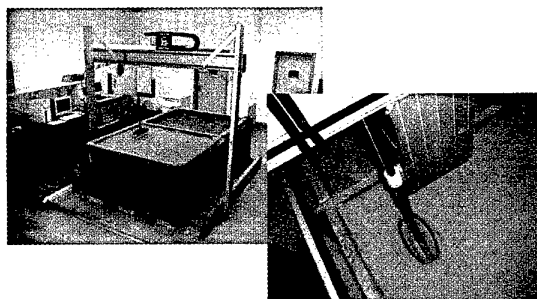
$$V_m = O\{V_c(s)\} = \hat{H}_{c0}^T(\hat{P}_i) \hat{\Gamma}_i \hat{H}_{c0}(\hat{P}_i)$$



ADVANCED PROCESSING FOR MD

- **Imaging**
build valuable image of the the metallic parts of the buried unknown target to distinguish a mine from a non mine object.
- **(Evaluated) polarizability tensor**
Find position (x,y,z) of target & (evaluated) polarizability tensor
- **Temporal signal**
use the time response to build a characteristic vector of the target (poles, etc.).

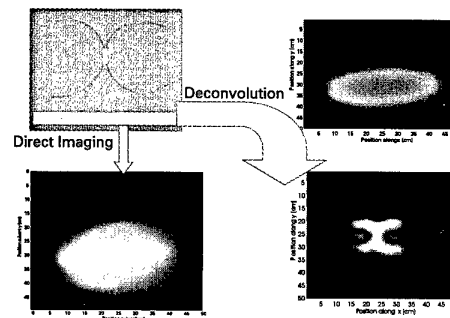
EXPERIMENTAL SETUP



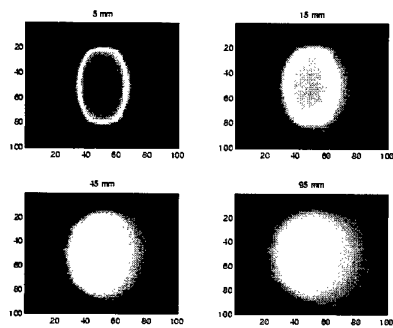
IMAGING

- Goal: build a visual representation of the audio signal.
- Problem: MD has an extended footprint \Rightarrow the raw image is blurred.
- Image restoration:
 - $G(x,y) = h(x,y)*T(x,y)+h$
 - find $T(x,y)$ knowing $G(x,y)$ or
 - restore the high frequency of the target spectrum without significant noise amplification.
 - used technique: Wiener filter

MD IMAGING



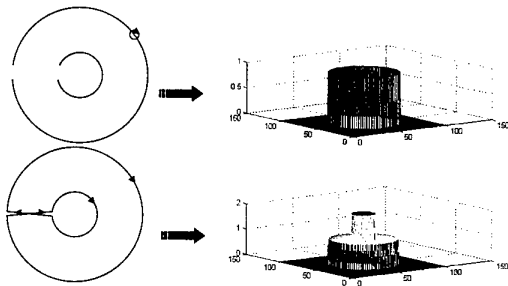
IMAGING KERNEL



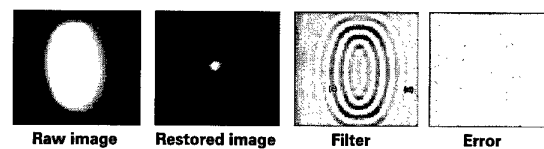
TARGET MODELS

Target type	Raw image	Kernel	Target function
Distribution of independent spherical dipoles	$V_n(x,y)$	$\left[\frac{B}{B_0} \right]^2$	$T(x,y) = \Gamma_{xx}(x,y) = \Gamma_{yy}(x,y) = \Gamma_{zz}(x,y)$
Distribution of independent horizontal loop like dipoles	$V_n(x,y)$	$B_{\theta_0}^2$	$T(x,y) = \Gamma_{xx}(x,y)$
Single planar extended closed winding	$\pm \sqrt{V_n(x,y)}$	$B_{\theta_0}^2$	$T(x,y) = \frac{N(x,y)}{\sqrt{a}}$ where $N(x,y)$ is the number of turns of the winding around the point (x,y) and $a = O\left(\frac{r^2 \mu_0 I_0}{Z_0(z)}\right)$ reflects the electrical characteristic of the winding.

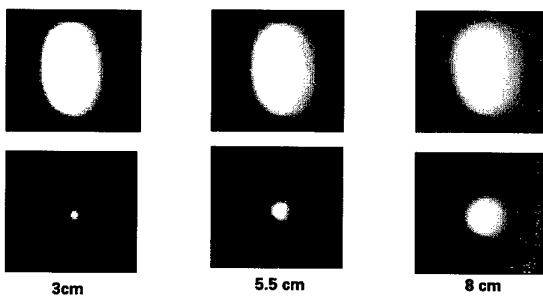
TARGET MODELS



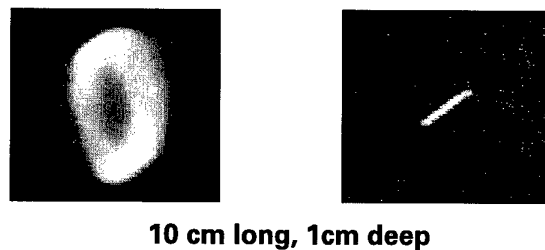
IMAGING OF A STEEL BALL (D=3CM)



IMAGING OF A STEEL BALL

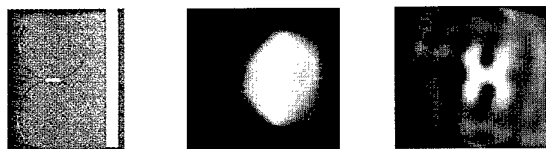


STRAIGHT COPPER WIRE



10 cm long, 1cm deep

X LIKE SHAPE



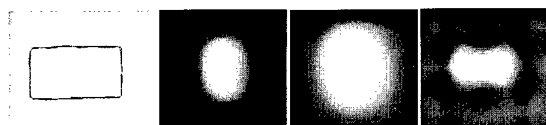
8x12cm, 4cm deep

OPEN FLAG



8x16cm, 4cm deep

CLOSED RECTANGLE



8x16cm, 8cm deep

MAGNETIC POLARIZABILITY

$$V(\rho_c) = \hat{B}^T (R_c (\rho_i - \rho_c)) \hat{\Gamma} \hat{B} (R_c (\rho_i - \rho_c))$$

\hat{B}	Magnetic induction field
R_c	Rotation of the detector coil
ρ_c	Position of the detector coil
ρ_i	Position of the target
V	Output of the detector
$\hat{\Gamma}$	Evaluated magnetic polarizability

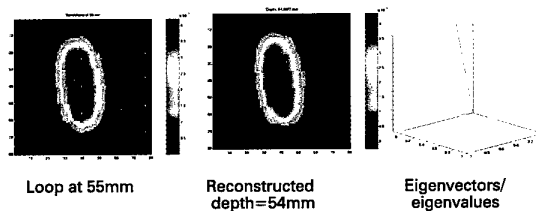
$$\rho_c, R_c \rightarrow \begin{bmatrix} \hat{\Gamma} & \rho_i \\ \hat{\Gamma} & \rho_i \end{bmatrix} \rightarrow V$$

Problem: evaluate the magnetic polarizability and the position of the target to fit the output of the detector

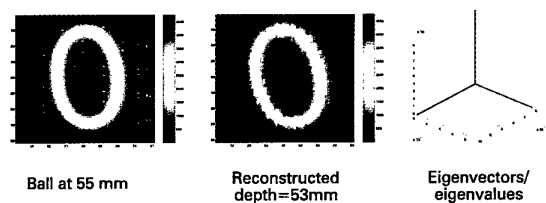
FIRST RESULTS

- **Simulation**
 - Simulate a **target** (loop, ball...) and generate a noisy signal
 - Compute theoretically the **magnetic field** generated by the metal detector
 - Simulate a **scanning** (horizontal + vertical movement)
- **Initial values**
 - horizontal position of single target can be known (maximum of the signal)
 - positions and orientations of the metal detector are known
- Perform a **non-linear minimization**
- Good convergence with noise up to 20-30 % on \hat{M}
- **Real data**
 - Sensitivity to orientation of the detector (scanning by X-Y table, orientation of the coil unknown)

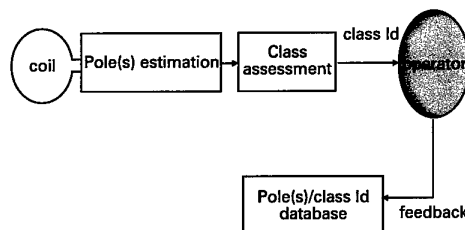
FIRST RESULTS (1)



FIRST RESULTS (2)



TEMPORAL SIGNAL



PRELIMINARY RESULTS

- **Samples of measured poles:**
 - steel ball ($D=4\text{cm}$) = $10\ \mu\text{s}$, $36\ \mu\text{s}$
 - Aluminium disk ($D=7\text{ cm}$, $t=5\text{ mm}$) = $4\ \mu\text{s}$, $46\ \mu\text{s}$
 - scissors = $12\ \mu\text{s}$, $38\ \mu\text{s}$
- Poles varies from one target to another but...

SIGNATURE INVARIANCE?

- Two similar mines: dominant pole is due to large closing ring.
- Oxidation increases resistance. Time constant decreases.
- Limit case: broken ring -> pole disappears



POSSIBLE SOLUTIONS

- **Adaptation to a specific minefield**
 - Historical/environmental factors could be homogeneous.
 - Learning on the minefield (recognize the signature of something already seen).
- **Use more generic features**
 - Symmetries
 - Aspect ratio
 - ...

CONCLUSIONS

Imaging

- target type (open/closed) must be known to select the right model (two cases may be tried).
- depth must be known (ongoing research)
- developed models appropriate to model (the tested) real targets.
- results are promising
- resolution decreases with depth (barbed wire was identified up to 10 cm)

CONCLUSION (2)

Signature

- Pole identification using the coil voltage temporal evolution (could be invariant on a given minefield)
- Position/depth + evaluated magnetic polarizability tensor evaluated for small targets (symmetries, etc.)

ONGOING WORK (1)

- **Imaging with manual scanning:**
 - development of a lightweight precise/cheap positioning system
 - restoration on an irregular grid.
- **Depth estimation.**
 - Imaging based: depth at which the 'best' image is obtained
 - single (discrete number) small targets: non-linear optimization.
- **Automatic adaptation of restoration parameter**

ONGOING WORK (2)

Technology oriented:

- **Induction source side**
Multicoil induction system to provide the ability to excite polarizability tensor's element independently
- **Backscattered field sensing side**
Array of punctual electronics magnetic sensors instead of a classical coil (large spatial integration).
- **Bistatic mode**
Fixed reception coil/moving excitation coil (classical MD?) \Rightarrow less hypothesis for imaging

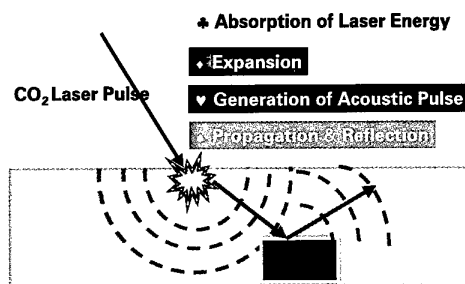
LASER INDUCED AND DETECTED ACOUSTIC DETECTION

Charles Di Marzio
Northeastern University

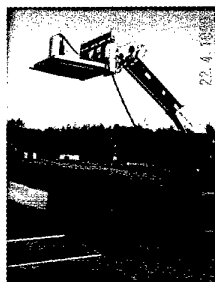
PROJECT MOTIVATION

- Why Acoustic Mine Detection
 - Demonstrated Success
 - Complementary technique of GPR & IR imaging.
- Why Laser Induced Acoustic Wave
 - Non-contact technique.
 - Easily coupled - over 90% laser radiation is absorbed in soil, sound is generated directly in the ground.
 - Flexible processing - scanning of light, focus laser spots and adjust the pulse width.

LASER INDUCED ACOUSTIC WAVE



LANDMINE DETECTION WITH ACOUSTIC WAVES



Platform
A.P. Hill
Calibration Lanes & Blind Test
April '99

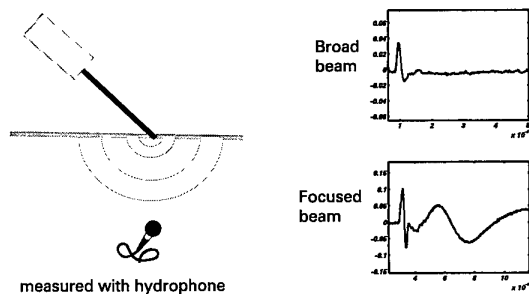
by Jim Sabatier, University of Mississippi

UNIVERSITY OF MISSISSIPPI BLIND TEST RESULTS FORT AP HILL, APR 99

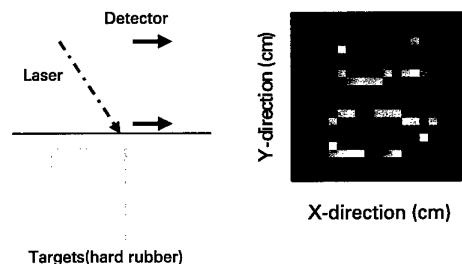
- 18 of 19 mines detected: 95% PD
 - 1 mine at 6 inches missed, but clearly present in data
- 40 remaining patches: 0.025/ m² FAR
 - 1 false alarms
- Of 10 clutter patches scanned:
 - None "sounded" an alarm

by Jim Sabatier, University of Mississippi

LASER INDUCED ACOUSTIC WAVES IN SAND AT NU

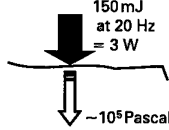
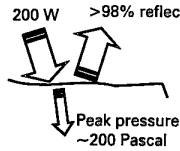


2-D SCAN FOR UNDERGROUND OBJECTS



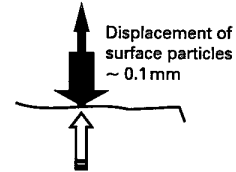
COMPARISON BETWEEN ACOUSTIC SOURCES

- Speakers Above Ground
 - 200 W
 - >98% reflection
 - Peak pressure ~200 Pascal
- Laser Heating of Soil
 - 150 mJ at 20 Hz = 3 W
 - ~10⁵ Pascal



COMPARISON BETWEEN ACOUSTIC RECEIVERS

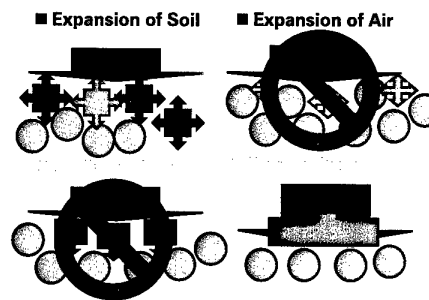
- Microphone Above Ground
 - <0.1%
- Laser Vibrometer
 - Displacement of surface particles ~0.1 mm



COMPARISON AMONG FOUR COMBINATIONS

- Two Source Types, Two Receiver Types
 - Speaker - Microphone: Crosstalk Low Sensitivity
 - Speaker - LDV: Good, Demonstrated
 - Laser Pulse - Microphone: Demonstrated in Lab
 - Laser Pulse - LDV: Potentially Best
- The Remaining Issues Relate to the Laser Pulse
 - Spatial Distribution of the Laser Energy on the Ground
 - Temporal Distribution of the Laser Energy
 - Pulse Shape
 - Pulse Repetition Frequency

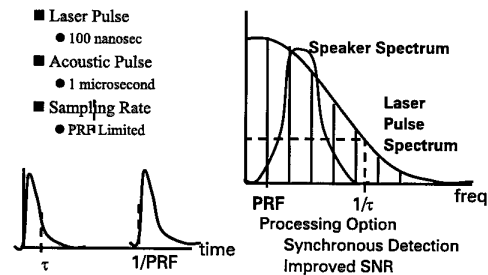
MECHANISMS OF SOUND GENERATION



LIKELY MECHANISMS OF SOUND GENERATION

- Large Beam
 - Low Power Density
 - Soil Heating
 - All Energy Absorbed
 - Direct Coupling
 - Compressional Wave
- Small Beam
 - High Power Density
 - Plasma Generation
 - Attenuated Beam
 - Sound Generation in Air
 - Slow Wave

LASER INDUCED ACOUSTIC PULSE SPECTRUM



SUMMARY OF CONCLUSIONS

- Acoustic waves can detect buried landmines
 - Low frequencies: provide 2-D imaging at 10 cm depths
 - High frequencies provide information on depth
 - Coupling energy into ground challenge
- Pulsed Lasers can produce acoustic signals in soil
 - Bandwidth ~ 1 MHz
 - Determined by interaction of light and soil
 - Mechanisms not well understood
- Research is needed to
 - Understand laser induced sound generation
 - Maximize energy at useful frequencies

USE OF ROBOTICALLY CONTROLLED SYSTEM FOR THE ENHANCEMENT OF MINE DETECTION

Robert Chesney
CCMAT, Canada

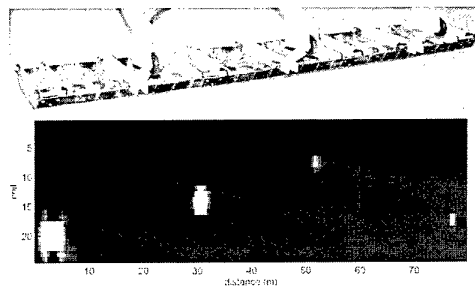
KEY DETECTION ISSUES

- Detection
- Discrimination
- Localization
- False Alarm Rate
- Coincident Detection

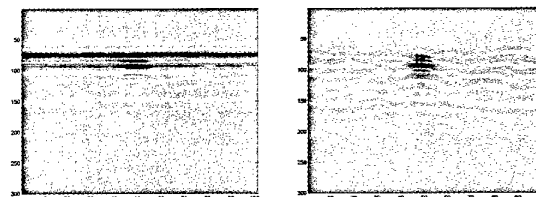
OPTIONS TO IMPROVE PERFORMANCE

- Use conventional detectors in unconventional ways
- Exploit more than one physical phenomena for detection

EMI DETECTOR ARRAYS



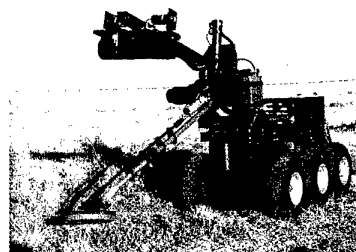
SCANNED GPR DETECTOR



SCANNER REQUIREMENTS

- Precise, repeatable, measured motion control
- Terrain measurement, obstacle detection and avoidance
- Detector head pitch and roll control
- Scanner motion control can be integrated with host vehicle motion control

ARTICULATED ROBOTIC SCANNER



ARS CAPABILITIES

- Terrain measurement with a scanning laser rangefinder
- detector path control for terrain following and obstacle avoidance
- scanning arm has controlled motion in:
 - scan arc;
 - longitudinal axis;
 - height;
 - detector head roll; and
 - pitch

ROBOTIC NEUTRALIZATION

- Geo-referenced localization allows multiple cooperating systems to both detect and remove objects that generate a detection

SUMMARY

- Spatially registered detector data is needed to fully exploit the capabilities of many detectors
- Uniform repeatable spatial sampling allows more straightforward data interpretation
- geo-registered data may be needed for some "system" scenarios

SESSION:
Detection of the Explosive

STATE OF THE ART IN NQR MINE DETECTION – AN OVERVIEW

Neil F. Peirson, M.D. Rowe, J.A.S. Smith

Chemistry Department, King's College, Strand, London, WC2R 2LS, U.K. and the NQR Consultancy, U.K. neil.peirson@kcl.ac.uk, mrowe @ch.kcl.ac.uk, john.smith@kcl.ac.uk

NUCLEAR QUADRUPOLE RESONANCE

Nuclear quadrupole resonance (NQR) spectroscopy provides a method of detecting a number of materials including the explosives RDX, PETN, tetryl and TNT that form the basis of almost all landmines [1]. The method as well as giving an unambiguous identification of the presence of the material can also provide quantitative information about the mass and position of explosive, which may be of further assistance in neutralising the mine.

NQR experiments can also provide information about the temperature or pressure experienced by a material and can probe intrinsic properties such as chemical composition, crystallinity, molecular structure, molecular motion and electronic environment.

The basis of the NQR experiment is the application of radio-frequency (r.f.) radiation to a sample. The response of the material is then detected and analysed. The r.f. is normally produced by a solenoid, spiral or loop constructed of copper wire or tape. The response signal is detected using the same or similar antenna. It is also necessary to use a power amplifier to increase the r.f. field projected from the coil, greater powers required when larger volumes are to be interrogated. A low noise amplifier is placed close to the receiving coil to amplify the signal (by say 60 dB) prior to quadrature detection.

The system for the generation of r.f. pulses and the detection of the response can be located on a single board. In fact, a NQR mine detector, excluding the probe head and power supply could be contained in the volume of a laptop PC. Thus a hand held as well as a vehicle mounted or vehicle-tethered system is practical.

IN THE FIELD

Advantages

NQR has a number of advantages as a method of mine detection. RDX, PETN, tetryl, TNT and other ^{14}N containing explosives can be detected. Each material has a unique fingerprint – not found in any other materials in the field. So the detection is immune to the presence of metal items, roots, vegetation, rocks, voids or the nature of the terrain. Equally, the method can be used in both wet and dry conditions, even in the presence of seawater.

The method is particularly suited to detecting mines with little or no metal content.

NQR is an inherently safe technique without the risks of radioactivity or ionising radiation. There is a very low potential risk to the operator or the environment.

Potential problems

Research into the application of NQR to mine detection has highlighted some areas that require further work. This has concentrated on sensitivity enhancement. The NQR method is capable of detecting sub-gram quantities of explosive. However, to detect quantities typical of landmines buried at depth requires special techniques to reduce the time involved to an acceptable period.

A second problem is the presence of sources of external interference such as radio stations or un-suppressed motors.

A third problem is caused by the generation of spurious responses from other materials following the r.f. pulse. These problems and recent methods to solve them are discussed in this poster.

Multiple Pulse Sequences

In the basic NQR experiment the signal is detected following a pulse, which cannot be repeated until the system has recovered. This process has a characteristic time, T_1 , which can range from for example 10 ms for RDX to 30 s for PETN. This restriction can be overcome by the use of spin-echoes.

The pulse spin-echo forms the basis of the use of the multiple pulse sequence (MPS) to enhance signal magnitude in a given time. In the NQR experiment the application of two pulses separated by a time, τ , generates an echo at t following the second pulse as well as responses to each of the individual pulses. Such echoes, also known in NMR and laser spectroscopies, are the result of refocusing coherent spin-states. A string of pulses in an MPS will each produce an echo as shown in Figure 1. These can be summed to produce a considerable increase in signal in a given time, since echoes can be collected every $\tau < T_1$ (e.g. typically for TNT $\tau = 2$ ms, $T_1 = 30$ s).

A large number of spin-echo sequences have been investigated using variations in the phase, length and repetition times of the pulses. Different sequences can be used to optimise the detection of different materials. For example, is achieved by the use of two sequences run consecutively. One is a simple MPS with an identical string of pulses (NPAPS), the second is the same except that the phase of alternate pulses is inverted (180° change). The resulting responses are summed to increase the signal and reduce the effects of temperature variation that can affect some MPS.

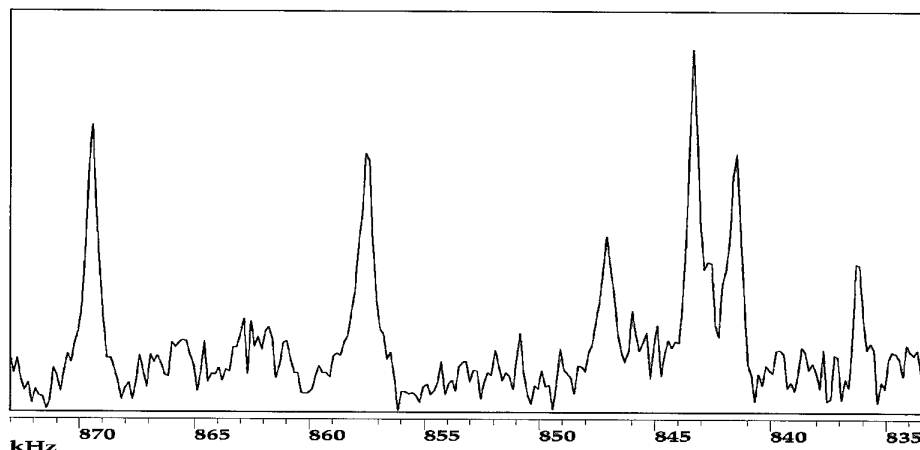


Figure 1: The room temperature NQR spectrum of TNT between 830 and 880 kHz.

SPURIOUS RESPONSES

Piezo-electric and ferro-magnetic can give responses to r.f. pulses, such spurious signals could mask true NQR signals. Piezo-electric responses produced by the interaction of the E-field of the r.f. pulse with materials such as sand. This can be eliminated by the use of a Faraday shield, but with some loss in sensitivity. The use of specifically designed pulse sequences can however remove both piezo-electric and ferro-magnetic responses without the loss in sensitivity. These sequences are based on the principle of phase equivalence [2]. This can be illustrated by reference to the sequences in Figure 2. The addition of a third MPS containing a string of identical pulses with inverted phase (180°) pulses allows the balancing of responses from each sequence to cancel spurious responses to the order of 30 dB.

INTERFERENCE

Interference can be picked up from external sources such as radio stations, un-suppressed motors etc. One method of eliminating such effects is the use of a pair of gradiometer coils [3]. Two coils are used in an anti-Helmholtz configuration to cancel the affect of distant sources of interference. The response from the sample will, however, be much stronger in one coil. This results in a signal close to that obtained from a single coil, but with significant rejection of external sources of interference.

CONCLUSIONS

NQR detection of landmines can be achieved in a wide variety of terrains. Most environmental factors have a limited effect on the NQR detection of landmines. The presence of piezo-electric and ferro-magnetic material or the effects of temperature variation can be overcome by a suitable choice of pulse sequence. The use of gradiometers and other methods can largely eliminate the effects of external interference.

Challenges still exist in increasing the sensitivity of the method so as to reduce the time for detection, whilst retaining the very low false alarm rate.

REFERENCES

- [1] M.D. Rowe and J.A.S. Smith, The detection of abandoned landmines, EUREL, 1996, p. 62-66.
- [2] N.F. Peirson and J.A.S. Smith, Method and apparatus for NQR testing a sample and pulse sequence for exciting NQR, U.K. patent application, GB 9503807.1
- [3] M.D. Rowe and J.A.S. Smith, Apparatus for and method of NQR testing a sample, U.K. patent application, GB 9804931.5

SESSION:
Sensor Fusion

CHARACTERIZATION AND FUSION OF MINE DETECTION SENSORS IN TERMS OF BELIEF FUNCTIONS

Nada Milisavljevic
RMA, B

INTRODUCTION - WHY FUSION?

- no single sensor solution of the overall problem:
 - / necessarily high detection rate
 - / highly imaginative nature
 - / creativity of mine producers
 - / most of times: lack of funding for humanitarian demining projects
- a way to go: to try to take the best from several complementary sensors

INTRODUCTION - WHY DS?

- in this domain of application:
 - the data:
 - basically numerical
 - not numerous enough for reliable statistical learning
 - highly variable (context, conditions)
 - do not give precise information on the type of mine
 - not every possible object can be modeled
- ⇒ need to appropriately model: ambiguity, uncertainty, ignorance, partial knowledge

INTRODUCTION - WHY DS AGAIN?

- to be able to easily include and model existing knowledge regarding:
 - chosen mine detection sensors
 - well-known mine laying principles
 - mines
 - objects that could be confused with mines
- *note* - approach is quite general, and just illustrated for these three sensors:
 - IR (infrared)
 - MD (imaging metal detector)
 - GPR (ground penetrating radar)

TWO-STEP APPROACH

- both levels modeled within DS framework first level - deciding whether an object is:
 - MO (metallic)
 - LMO (low-metal content)
 - NMO (non-metallic)
- second level - analyzing the chosen path(s) (the chosen type of object) in more detail, i.e. whether this object is:
 - MR (mine of regular shape) - MMR, LMMR, NMMR
 - MI (mine of irregular shape) - MMI, LMMI, NMMI
 - FR (friend of regular shape) - MFR, LMFR, NMFR
 - FI (friend of irregular shape) - MFI, LMFI, NMFI

FIRST LEVEL

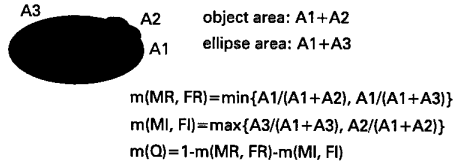
- MO, LMO, NMO create frame of discernment
- criteria:
 - area on MD image
 - strength of MD response
 - comparison of MD and IR area
 - comparison of MD and GPR area
- result: the most expectable type(s) of object - either MO, LMO or NMO, or some of their combinations
- based on that, a concrete, chosen type is further analyzed in the next, second step

SECOND LEVEL - EXAMPLE FOR MO

- MMR, MMI, FMR, FMI create frame of discernment
- criteria:
 - for each of the three sensors:
 - shape ellipticity
 - shape elongation
 - area/size
 - for MD:
 - burial depth
 - for GPR:
 - depth dimension
 - depth information comparison with MD
(an original way to account for links between sensors)

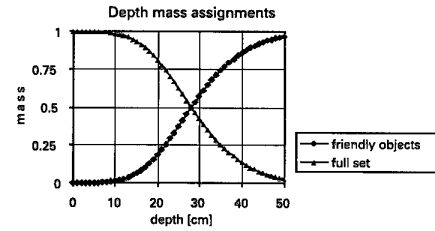
EXAMPLE OF MODELING - ELLIPSE FITTING -

- focal elements: {MMR, MFR}, {MMI, MFI}, \emptyset
- an ellipse fitting algorithm based on the *randomized Hough transform*



MODELING - EXAMPLE OF BURIAL DEPTH

focal elements: {FR, FI}, \emptyset



DISCOUNTING

- behavior of each of these sensors strongly scenario-dependent, referring to:
 - quality of the acquired data
 - detection ability/reliability
 - types of objects under analysis
- need for including influence of various factors on the obtained results, i.e. On:
 - sensor's confidence when judging about some criterion
 - importance of each criterion
 - deminer's confidence in each of the sensors

DISCOUNTING FACTORS

- consist of three types of parameters:
 - g_{ij} - confidence of sensor j in its assessment when judging about criterion i ($[0,1]$)
 - b_i - level of importance of criterion i
 - s_j - deminer's confidence in sensor j
- each of the factors is used in successive discounting, so the global factor is:

$$d_{ij} = 1 - g_{ij} \cdot \frac{s_j}{s_{scale}} \cdot \frac{b_i}{b_{scale}}$$

COMBINATION

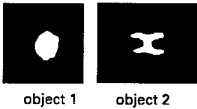
- DS rule in unnormalized form:

$$m(A) = \sum_{i,j} m_i(A_i) \cdot m_j(B_j)$$

$A_i \cap B_j = A$

(result - no focal element containing mines alone, since we only know when something cannot be a mine; It is in accordance with the fact that mines must not be missed)

- test images:



object 1 object 2

- four cases analyzed

RESULTING MASSES

Masses	Cases			
	Case 1	Case 2	Case 3	Case 4
m(FR)	0.0585	0.00023	0.0127	0.04
m(FI)	1.6e-7	0.01124	8.8e-6	3.9e-4
m(FR, FI)	1.8e-12	4.26e-14	6.9e-13	5.9e-4
m(MR, FR)	0.9279	0.0146	0.2021	0.845
m(MI, FI)	2.5e-6	0.72	1.5e-4	0.0666
m(\emptyset)	2.8e-11	2.73e-12	1.1e-11	0.009
m(Q)	0.0135	0.2539	0.785	0.0384

cautious 1) mine 1) friend 1) something else 1) mine
 approach: 2) friend 2) mine 2) mine 2) friend
 3) something else 3) something else 3) friend 3) something else
 ("ordered guess list")

ESTIMATION OF CONFIDENCE DEGREES

- Three ways:
 - finding interval [Bel, Pl] for each of the classes
 - comparing believes and plausibilities of different classes
 - calculating pignistic probabilities

FINAL REMARKS

- one of advantages of the method: inclusion of existing knowledge about the problem
- first results are very promising, illustrated on a few examples here
- similarly, a complete model is developed and tested for:
 - LMO and NMO cases, as well as first level
 - detail analysis of discounting factors
 - analysis of internal conflicts of sensors, allowing to distinguish cases when sensors do not refer to the same object (when conflict between sensors exceeds significantly internal conflicts)

SENSOR FUSION AND THERMAL MODELING

Brian Baertlein
Ohio State University

OUTLINE

- Sensor fusion
 - Optimizing performance for small sample sets
 - Feature-level approaches
 - Decision-level approaches
- Case study
- Modeling IR signatures of buried mines
 - Signature model
 - Thermal physics
 - Radiometry
 - Clutter sources
 - Rough surfaces
 - Random emissivity
 - Inhomogeneous soil water distribution
- Example results

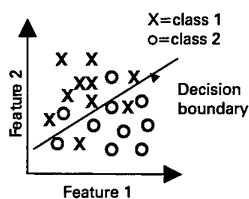
FUSION WITH SMALL DATA SETS: THEORY AND PRACTICE

- **In theory, more information is better**
 - Fusing more sensors cannot degrade performance
 - Feature-level fusion cannot be worse than decision-level fusion
 - Adding more features cannot degrade performance
- **In practice, including ineffective sensors or features can hinder performance (Hughes, 1968)**
 - Fused data sets always have higher dimension (more training data required, especially for feature-level fusion)
 - Problems are related to small data sets: probability densities (or classifier decision boundaries) cannot be determined from data)
- **Multisensor data sets are relatively small since, size of data set always limited by slowest, least-reliable sensor**
- **How can we make best use of available data?**
 - Statistical Learning Theory (SLT) provides theoretical framework
 - Algorithms not limited to small data sets

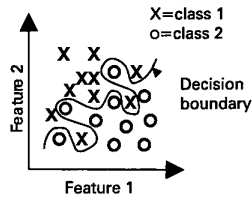
SLT RELATES COMPLEXITY AND RELIABILITY

- Reliability (confidence) decreases with increasing complexity

Low complexity, high training error,
high reliability/confidence

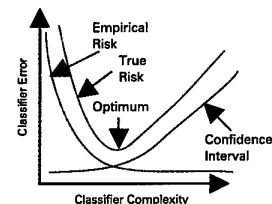


High complexity, small training error,
low reliability/confidence



OPTIMIZING FUSION RISK USING STRUCTURE RISK MINIMIZATION (SRM)

- Let R be true risk (error rate) of a fusion algorithm
- Let R_{emp} be the "empirical" risk estimated from the available data
- Can show for N samples $R \leq R_{emp} + \Phi(h/N)$ where F is a monotonic function (confidence interval) and h measures complexity
- True risk has a minimum for optimal complexity
- Use numerical methods to find find optimum (SRM)

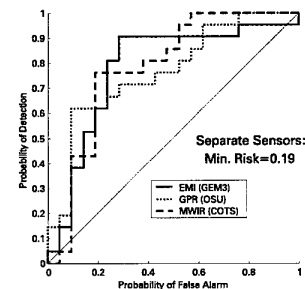


CASE STUDY

- Data acquired at Fort A. P. Hill, Virginia, USA, Site 71A, JUXOCO Lanes:
 - 25 x 5 m calibration lane
 - 27 deactivated mines and 32 clutter objects
 - Essentially free of unknown metallic clutter
 - Mines have all metal components, but lack HE (good EMI surrogates, but uncertain IR properties)
 - Target positions accurately known
- Sensor suite used in this study:
 - GEM-3 EMI sensor (data collected by Duke U.)
 - OSU-developed GPR + dielectric rod antenna (1-6 GHz)
 - COTS MWIR camera (2.2-4.6 μ m, operated at night)
- 42 sites with data available from all sensors (21 targets, 21 clutter)
- No "blank" sites

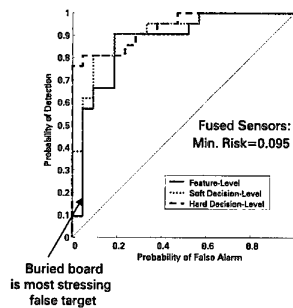
OPTIMIZED SENSOR DETECTORS

- Use SRM technique to identify best detector for each sensor
- Use "leave-one-out" method to estimate true risk
- Form ROC curves using optimized detectors
- Comparable performance among sensors. No sensor has a clear advantage.



OPTIMIZED FUSION PERFORMANCE

- Three fusion methods
 - Feature-level fusion optimized with concatenated feature sets.
 - Optimized hard decision fusion uses majority voting rule and threshold remapping.
 - Soft-decision fusion uses remapped classifier outputs
- Methods comparable except for very small P_{fa} where hard decision fusion is superior (fused feature data has higher dimension)



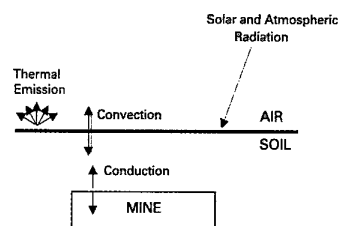
IR SIGNATURE MODELING

- Objective: Improve understanding of passive IR signatures of buried land mines
 - Develop better detection algorithms
 - Guide sensor deployment
- Mine signature has many contributing physical processes
 - Thermal phenomena
 - Radiometric components
 - Soil water effect on thermal and radiometric characteristics
- Several potential sources of clutter
 - Rough surface
 - Random surface emissivity
 - Non-uniform soil water distribution

Developed under support from ARO MURI on Humanitarian Demining and ARL Federated Labs Program

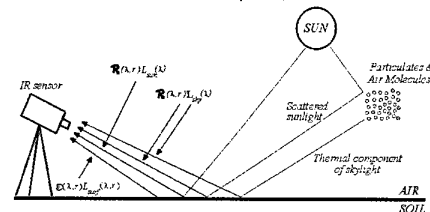
THERMAL PROCESSES

- Conduction in the soil and at the soil-mine interface. (Note: soil conductivity \gg TNT conductivity)
- Convective heat transfer at the soil-air interface
- Radiative heat transfer involving contributions from sun and atmosphere
- Other potential mechanisms include soil water flow, evaporation at surface (not considered)



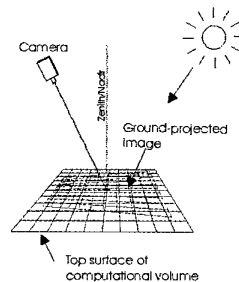
RADIOMETRIC COMPONENTS OF IR IMAGERY

- Thermal emissions from the soil surface
- Soil reflected sunlight
- Soil reflected skylight (scattered sunlight + thermal emissions from the atmosphere)



RADIOMETRIC MODEL

- Virtual IR Sensor:
 - MWIR device, 4.4-5.0 μm
 - 160 (h) x 120 (v) pixels
 - 10° sensor zenith angle
- Surface properties
 - Spatially constant emissivity = 0.90
 - Diffuse reflecting rough surface
- Solar irradiance parameters
 - Clear sky illuminating spectra (MODTRAN 4)
 - 30° N latitude, 83° W longitude (Columbus, OH)
 - April 3 (sunrise ~700, sunset ~1800)

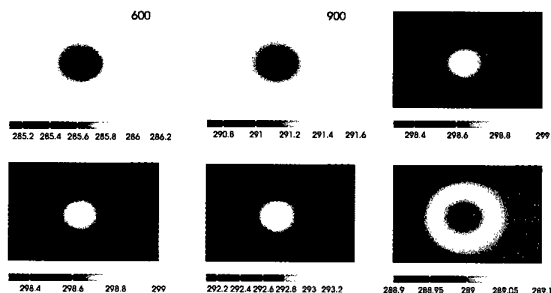


THERMAL MINE MODEL: NVESD SURROGATE

- Surrogate used as a model of a "representative" anti-tank (AT) mine
- Cylindrical shape, 25 cm diameter, 8.3 cm thickness
- Primary filling is TNT (RTV used in surrogate construction)
- Simple design (useful for subsequent validation testing)

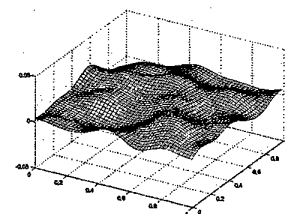


RADIOMETRIC MODEL RESULTS: AT MINE, SMOOTH SURFACE



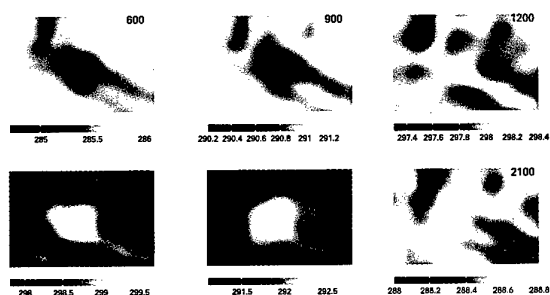
CLUTTER SOURCES: ROUGH SURFACE

- Surface roughness clutters IR imagery via
 - Uneven thermal heating
 - Variable surface reflections
- Model using Gaussian distributed surface spectrum, user specified correlation length
- Experimental measurements of typical correlations in progress

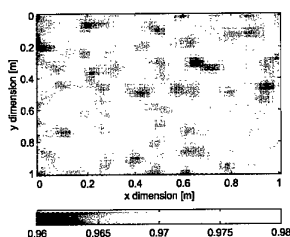


Example surface realization with 20 cm correlation length, 3 cm height

RADIOMETRIC MODEL RESULTS: AT MINE, ROUGH SURFACE

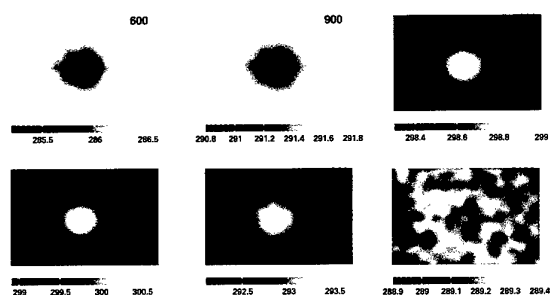


VARIATIONS IN SOIL EMISSIVITY

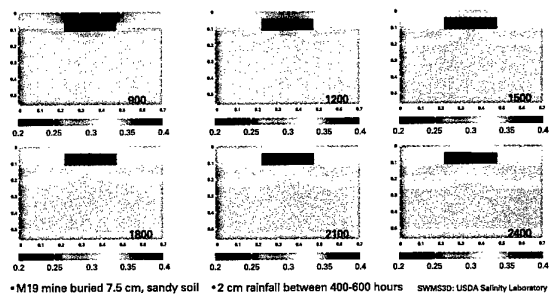


- Soil reflectivity of soil at 4.4-5.0 mm varies in the 10 - 20% range
- Model using Gaussian distributed surface emissivity with correlation length 5 cm

EFFECT OF EMISSIVITY VARIATIONS ON MINE SIGNATURE

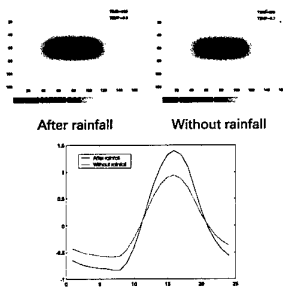


MINE AFFECTS SOIL WATER DISTRIBUTION



PRELIMINARY ANALYSIS OF SOIL WATER EFFECT ON THERMAL SIGNATURE

- Preliminary study done to evaluate importance of soil water
- Emplace M19 mine at 7.5 cm depth.
- Fix soil water content (static, decoupled from thermal model)
- Simulate diurnal thermal heating
- MWIR camera at 30° elevation angle
- Results show little difference in spatial shape of signature, but improved contrast after rainfall



SUMMARY

- Fusion
 - Fusion algorithm/classifier must be matched to data set size and dimensions to benefit from additional information.
 - Statistical learning theory and structural risk minimization provide constructive mechanism for optimizing fusion performance
 - To make best use of available data
 - Optimize performance of classifier fusion algorithms using SRM concepts
 - Optimize fusion rule and local decision criteria of hard-decision algorithms
- IR Modeling
 - Nonmetallic mines block thermal flux (TNT is a better insulator than soil).
 - Phase of mine and clutter signatures often different. Potential for using time-space filtering. (Lundberg and Gu, SPIE AeroSense '00)
 - Random surface emissivity can be a significant contributor to clutter.
 - Preliminary analysis suggests rainfall will improve mine contrast. Soil water is a potential clutter source.

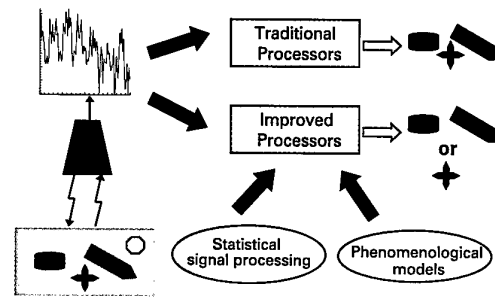
EMI, GPR AND MAG SIGNAL PROCESSING AND FUSION

Leslie Collins
Duke University

APPROACH

- Develop *optimal/sub-optimal* statistical signal processing algorithms that incorporate
 - the underlying physics characteristic of the sensor, the target, and clutter, etc., or features based on the physics
 - statistical nature of the signal
 - uncertainties associated with a variety of target/clutter objects present
 - uncertainties associated with sensing environment (underground object position and orientation)
 - noise subjected to the sensor
- Traditional sensor and data processing techniques, which is usually a threshold test on raw data, suffer from large false alarm rates.

APPROACH

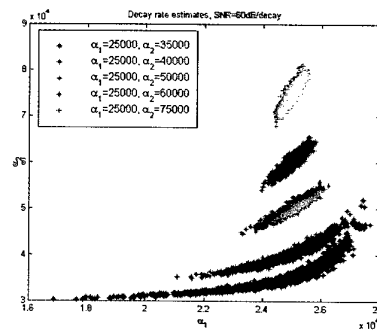
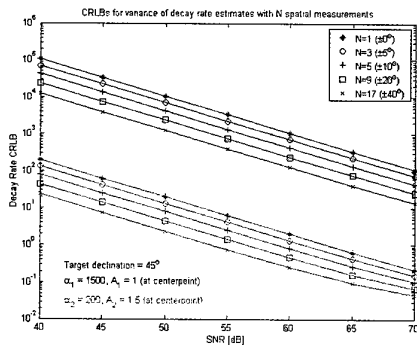


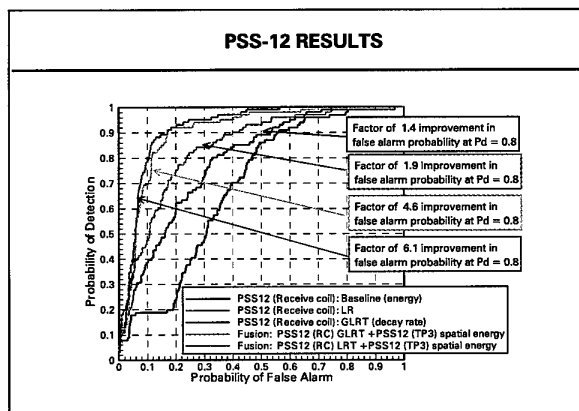
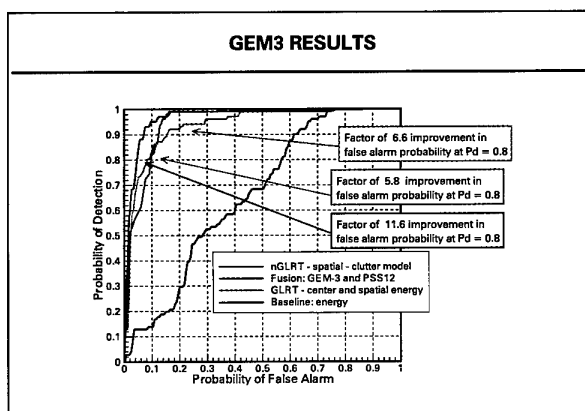
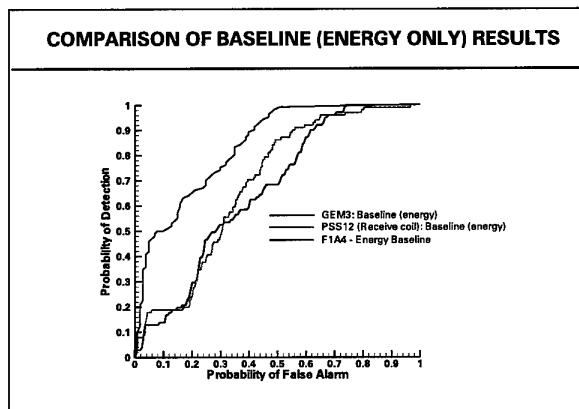
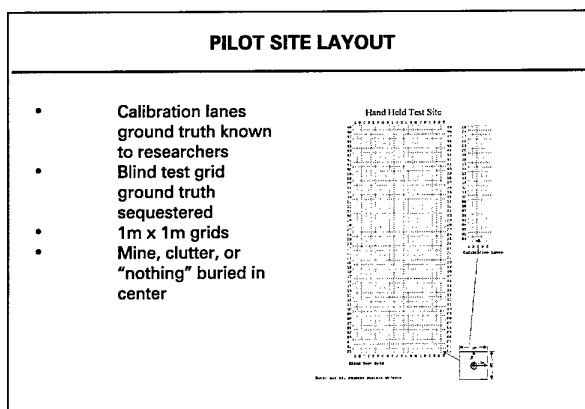
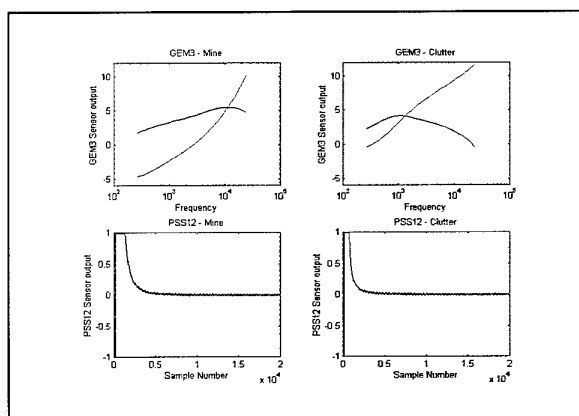
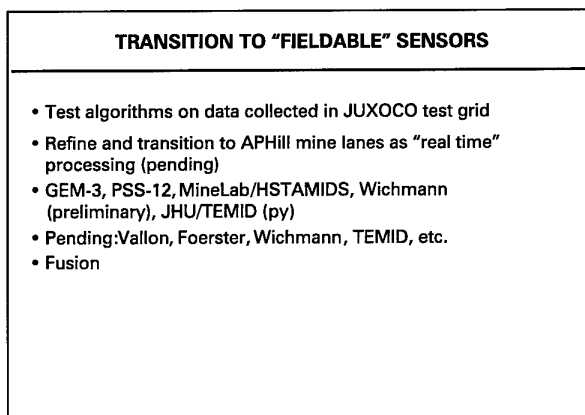
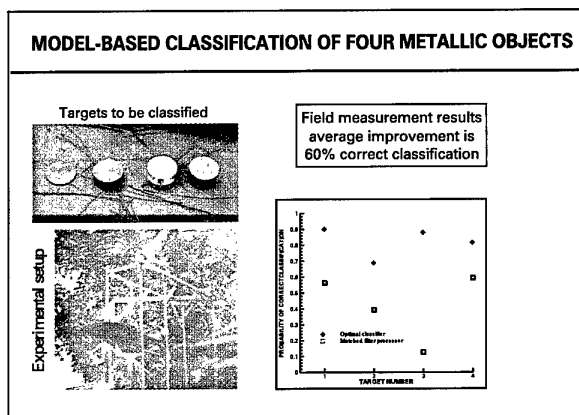
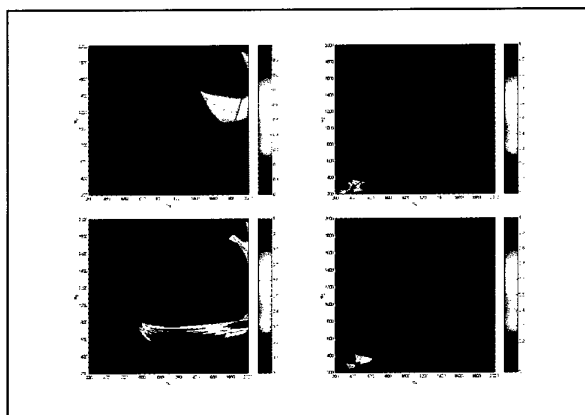
PROGRAMS AND PROGRESS

- MURI
 - Theoretical performance bounds: EMI
 - Physics-based statistical signal processing and sensor fusion
- DARPA
 - Backgrounds data: EMI, MAG, GPR
- JUXOCO
 - Statistical signal processing algorithms (blind test)
 - PSS12, GEM3/MineLab JHU/Emid Wichmann...
- HSTAMIDS, GSTAMIDS
 - EMI signal processing, fusion
- SERDP
 - EMI, MAG, GPR signal processing for UXO detect/discrim

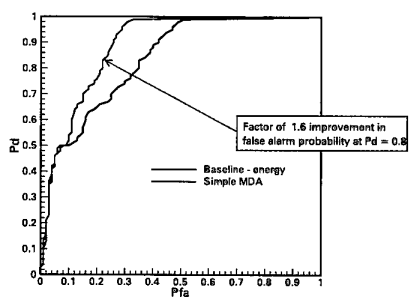
EMI PROCESSING PERFORMANCE BOUNDS

- EMI signal modeled as weighted sum of decaying exponentials
- Derived CRLB
 - System design
 - Performance evaluation
- Optimal processors for detection and classification
- Time-domain and frequency-domain performance comparison





MINELAB F1A4 - PRELIMINARY PROCESSING RESULT



CONCLUSIONS

- Statistical signal processing techniques offer substantial performance gains over traditional threshold-based algorithms.
- Spatial information (arrays?) Provide additional performance gains
- Other GPR, MAG and EMI algorithms and fusion approaches (UXO, landmines) can be described at the poster...

SENSOR FUSION OF GPR, MD AND TIR

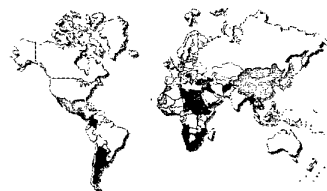
Piet Schwering
TNL, NL

OUTLINE

- Introduction
- Performance evaluation and optimisation
- Decision-level sensor-fusion methods
- Experiments and results
- Conclusions
- Future work/discussion

LAND-MINE DETECTION PROBLEM

- > 110 million land-mines world wide (UN)
- Commonly used detection method: prodding



source: <http://www.demining.brtrc.com/maps/WORLD.HTM>

CURRENT SINGLE SENSORS PERFORMANCE

At GEODE test lane:

- Metal detector (MD)
 - detects 60% with 1 false alarm / m²
- Ground Penetrating Radar (GPR)
 - detects 90% with 5 false alarms / m²
- Thermal Infrared Camera (TIR)
 - detects 50% with 0.2 false alarms / m²

Requirements: better than 99.6% with 0.1 FA / M²

➔ Sensor fusion techniques necessary

LEVELS OF SENSOR-FUSION TECHNIQUES

- Data-level
 - multiple similar sensors (image fusion)
- Feature-level
 - measured object features (size, metal content, volume)
- Decision-level
 - hard decisions (yes / no)
 - soft decisions (probabilities)

HUMANITARIAN DEMINING ACTIVITIES AT TNO-FEL

- HOM2000 phase A and B
- EU Projects: GEODE and LOTUS
- ➔ PhD: sensor-fusion and polarimetric infrared
 - Frank Cremer
 - Prof Dr. Ir. J.T. Fokkema (Applied geophysics, Delft University of Technology (DUT))
 - Prof Dr. I.T. Young (pattern recognition, DUT)
- PhD: signal processing for GPR (Jan Rhebergen)
- IPPTC
- Workshop

OUTLINE

- Introduction
- ➔ Performance evaluation and optimisation
- Decision-level sensor-fusion methods
- Experiments and results
- Conclusions
- Future work/discussion

PERFORMANCE EVALUATION (SCOOP)

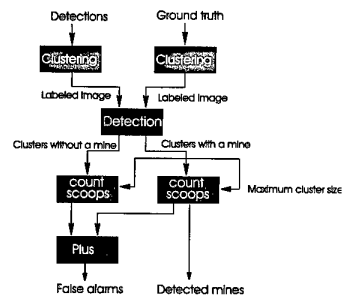
Traditional options:

- Counting number of false alarms
 - what if the false alarm areas are very large?
- Percentage of area
 - what if the detections are very wide spread?

SCOOP: Split Clusters On Oversized Patches

- uses both the distribution and the size
- result: number of scoop size areas to verify

SCOOP IMPLEMENTATION



PERFORMANCE EVALUATION

How to compare detection results of different sensors or fusion methods?

Detection results expressed as

- detected mines and false alarms / m^2
- expected costs
 - which cost function?
- receiver operator characteristics (ROC) curves

ROC THEORY

2 classifiers

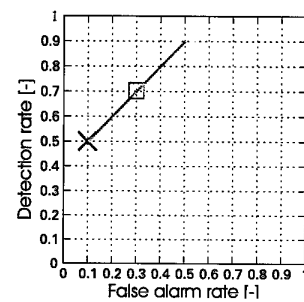
- different threshold

Performance

- no ranking
- except for known costs

Interpolation

- division of data set
- no improvement for linear costs



ROC THEORY (2)

Concave points

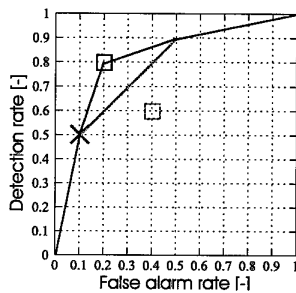
- perform worse

Convex points

- perform better

Parameter optimisation

- select only convex points



LEAVE-ONE-OUT EVALUATION METHOD

Evaluation options for small data set:

Training and evaluation on one set

- optimistically biased results

Creation of independent training and evaluation set

Training set consists of $n-1$ samples (mines)

Parameters are obtained on training set

Method is evaluated on single test sample

Repeat on all samples as test set and sum detections and false alarms

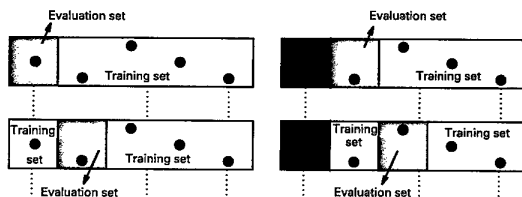
LEAVE-ONE-OUT EVALUATION METHOD (2)

Target training set

3 100% detection

3 select lowest false alarm rate

Remove mines in specific order for <100% detection



OUTLINE

- Introduction
- Performance evaluation and optimisation
- ◆ Decision-level sensor-fusion methods
- Experiments and results
- Conclusions
- Future work/discussion

SENSOR-FUSION METHODS

Decision-level sensor-fusion

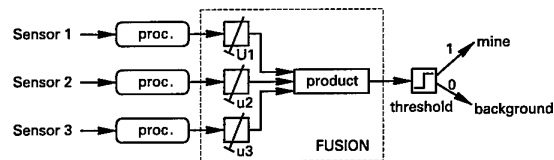
- incorporates knowledge of sensor experts
- applicable to physically different sensors
- data abstraction: confidence level
- reduction of data: less training parameters

Methods

- Naive Bayes
- Dempster - Shafer
- Fuzzy probabilities
- Optimal voting
- Rule-based

NAÏVE BAYES

- Assumed independence of sensors
- Scaling of inputs to adapt influence of each sensor
- Confidence level proportional to likelihood ratio

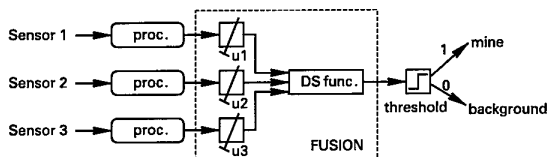


DEMPSTER - SHAFER

Adaptable uncertainty mass: $m(m \cup b) = u$

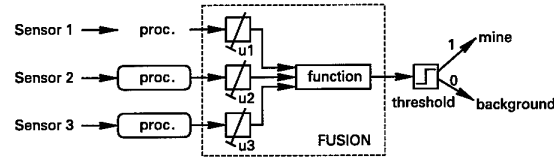
Mine probability mass: $m(m) = (1-u) c$

Background probability mass: $m(b) = (1-u) (1-c)$



FUZZY PROBABILITIES

- Gaussian kernel centered around confidence level
- Parameter 'u' determines kernel width
- Output: intersection + center of area

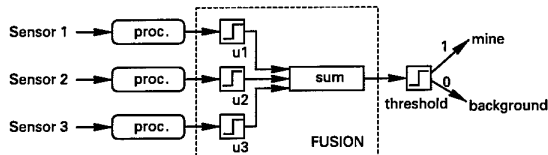


OPTIMAL VOTING

■ Threshold on each sensor

■ Final threshold:

- 1 vote (or voting)
- 2 votes
- 3 votes (and voting)

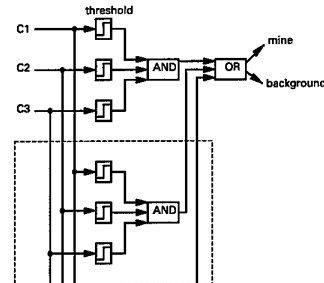


RULE-BASED FUSION

■ Thresholds on confidence values

Optimisation:

- partly exhaustive search
- partly using heuristics



BASELINE: BEST SENSOR

■ Implementation

- select sensor and threshold with best performance
- evaluate on training set

■ Simplest form of sensor-fusion

Goal of sensor-fusion methods

- improve over baseline

OUTLINE

■ Introduction

■ Performance evaluation and optimisation

■ Decision-level sensor-fusion methods

➔ Experiments and results

■ Conclusions

■ Future work/discussion

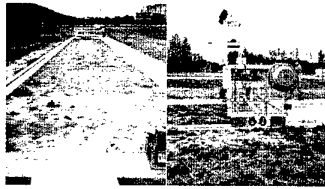
EXPERIMENTS: DATA ACQUISITION (GEODE)

- Förster metal detector
- Emrad Ground Penetrating Radar (GPR)
- Marconi Infrared Camera

Test lane 25x1m

- 26 mine targets
- 6 FA targets

Thomson CSF



EXPERIMENT SETUP (GEODE)

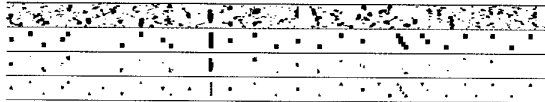
- Confidence levels for each sensor
 - related to probabilities
 - produced by partners: sensor experts
- Grid size $2.5 \times 2.5 \text{ cm}^2$: 1000 x 40 grid cells
- Fusion on individual grid cells
- Evaluation method
 - SCOOP: false alarm per m^2 and detection rate
 - Leave-one-out: independent training + evaluation set
- Sensors optimised on complete data set

SENSOR PROCESSING: EMRAD GPR

Processing steps

- Layer removal, time of arrival alignment
- Energy detection
- Projection on surface
- Threshold: 6 levels
- TNO: spatial processing

Results:



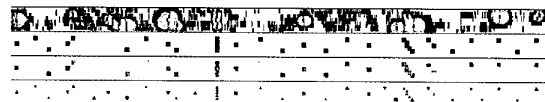
SENSOR PROCESSING: FÖRSTER MD

Minex 2FD dual frequency metal detector

Processing steps

- metal objects determined by zero crossings
- alignment of objects on different lanes
- blind areas (signal strength)

Results:



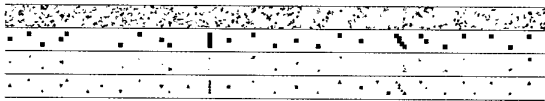
INFRARED PROCESSING (TNO)

IAI/TAMAN 3- μm Infrared Camera 320x240 pixels

Processing steps

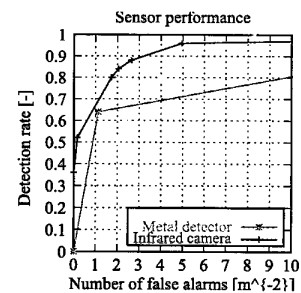
- resampling to grid cell size (local maximum)
- find blobs using multiple threshold
- local contrast enhancement

Results:



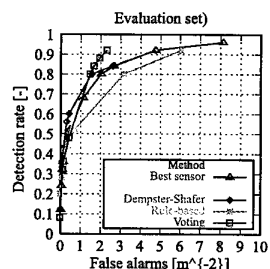
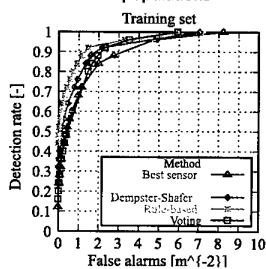
SINGLE SENSOR PERFORMANCE

- Threshold on confidence level
- Evaluation with SCOOP



LEAVE-ONE-OUT RESULTS

Method's own populations



LEAVE-ONE-OUT RESULTS

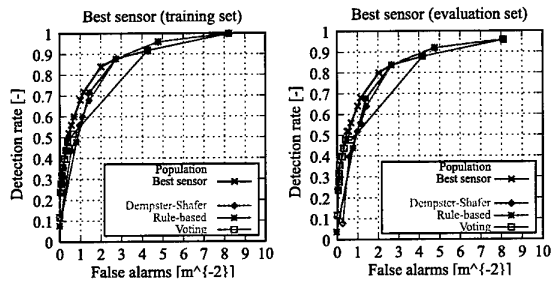
Training set

- All methods equal or better than best sensor
- Rule-based method performs best

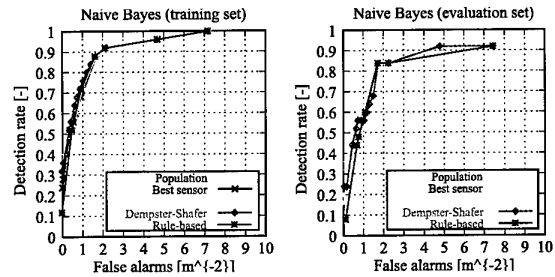
Evaluation set

- Naïve Bayes, Dempster - Shafer and voting still better than best sensor
- Rule-based method falls back drastically
- Voting is stable at high false detection rates
 - OR voting chosen

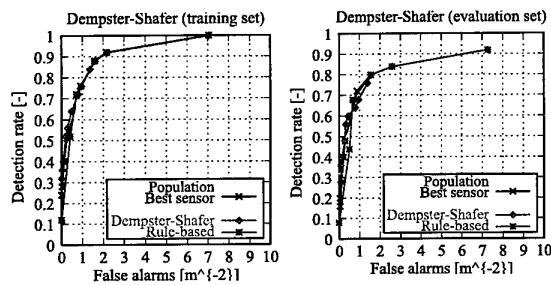
INFLUENCE OF POPULATIONS: BEST SENSOR



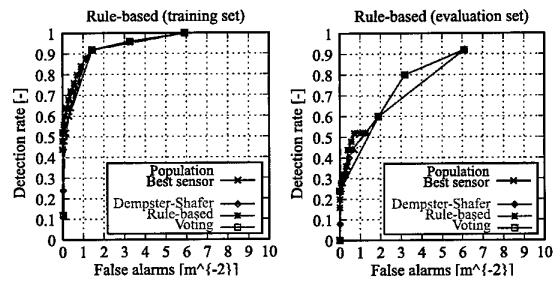
INFLUENCE OF POPULATIONS: NAÏVE BAYES



INFLUENCE OF POPULATIONS: DEMPSTER-SHAFER



INFLUENCE OF POPULATIONS: RULE-BASED



RESULTS OF POPULATIONS ANALYSES

- Differences between populations small
- Populations results for Fuzzy Probabilities and Voting not shown
- Results of different populations give an indication of sensitivity of method
- Difference between populations within one method is sometimes smaller than differences between methods

'REAL WORLD' PERFORMANCE

What if a larger data set is used?

- Training set
 - Performance will decrease
 - Parameters will be optimally estimated
- Evaluation set
 - More statistics available
 - Performance will increase towards the training set

Conclusion: expected performance will be in between current training and evaluation set performances

OUTLINE

- Introduction
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CONCLUSIONS

- Training set
 - All evaluated methods better than best sensor
- Evaluation set
 - Except for rule-based methods perform equal or better than best sensor
 - Large performance decrease for rule based fusion
 - Voting stable for high detection rates

Moderate influence of populations

CONCLUSIONS

- data recorded and analyzed in different soils and weather
- different evaluation techniques
- first order working fusion algorithms
 - also sensor based object detection
- improve on
 - feature fusion
 - (physical) model based
 - scenario dependence a-priori information

FUTURE WORK

Data set

- Larger data set: EU, national projects
- Verify with separate training and evaluation set

Fusion

- Feature level fusion
- Fusion at different physical depths
- More robust fusion methods

Sensor improvement

- For example polarimetric infrared

DISCUSSION

- Feature level fusion
 - object association?
 - which features?
- Fusion using depth information
 - two fusion maps: surface and buried
- Substitute for SCOOP (evaluation is slow)
 - SCOOP does not take shape into account
 - Larger grid?
- Robust fusion
 - how can more robust parameters be chosen?

SESSION:
Signatures

JOINT MULTI-SENSOR MINE SIGNATURE MEASUREMENT CAMPAIGN

Patrick Verlinde
RMA, B

OVERVIEW

- Objectives
- Experimental setup
- Layout of JRC test mine field
- Baseline outline for each soil (plot)
- Resource providers
- Core sensor list
- Management structure
- Milestones in 2000

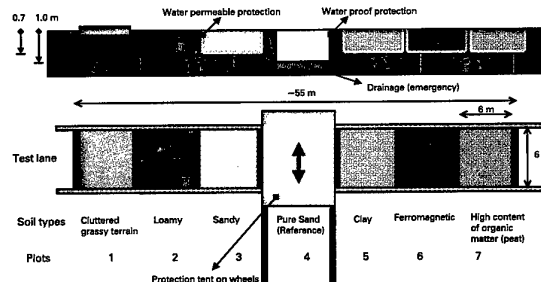
OBJECTIVES

- To organize and execute an experimental campaign for collection of data of buried landmines with multiple sensors.
- To make these multi-sensor data sets widely available to researchers and developers working on
 - sensor fusion,
 - signal processing for improved detection and identification of landmines,
 - assessing the role of the operator in the detection process, etc...

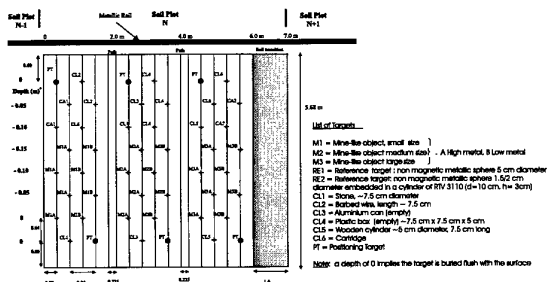
EXPERIMENTAL SETUP

- The JRC outdoor test facility (6 x 80 m) will house the test minefield
- Six test strips, are foreseen which will be complemented by one reference strip, located in the middle of the test minefield.
- There will be two XY-scanning tables, one for slow scanning devices and one for faster sensors or for operating more sensors at the same time.

LAYOUT OF JRC TEST MINE FIELD



PROPOSED BASELINE LAYOUT FOR EACH PLOT (REV. 11/07/00)



PROPOSED BASELINE LAYOUT FOR EACH PLOT (REV. 11/07/00)

List of Targets

- M1 = Mine-like object, small size }
M2 = Mine-like object medium size } - A High metal, B Low metal
M3 = Mine-like object large size }
RE1 = Reference target : non magnetic metallic sphere 5 cm diameter
RE2 = Reference target: non magnetic metallic sphere 1.5/2 cm diameter
embedded in a cylinder of RTV 3110 (d=10 cm, h= 3cm)
CL1 = Stone, ~7.5 cm diameter
CL2 = Barbed wire, length ~ 7.5 cm
CL3 = Aluminium can (empty)
CL4 = Plastic box (empty) ~7.5 cm x 7.5 cm x 5 cm
CL5 = Wooden cylinder ~5 cm diameter, 7.5 cm long
CL6 = Cartridge
PT = Positioning Target

Note: a depth of 0 implies the target is buried flush with the surface

LIST OF OBJECTS

- 24 mine surrogates per soil type: 4 identical examples of 3 different sizes each one coming in two different metal contents
- 14 clutter objects per soil type
- 6 positioning objects per soil type (2 per subplot)
- 4 reference targets per soil type

RESOURCE PROVIDERS

- DLR (GE): sensors;
- FGAN (GE): sensors;
- JRC (EU): general support, sensors, test facilities, funding, general scientific project lead;
- RMA (BE): sensors, general project management;
- TNO (NL): sensors;
- Other national research centres to join [e. g. ONERA (FR), FOA (SW), DERA (GB)];
- Geneva International Centre for Humanitarian Demining is invited to act as link to the user community.

CORE SENSOR LIST FOR 2000

- 2 Metal Detectors (MD): pulsed and CW
- 1 Ground Penetrating Radar (GPR)
- 1 Microwave Radiometer (1-10 GHz)
- 3 Thermal Infrared (3-5 and 8-14 μ m + quantum well)
- + Optical (Visible, Near Infrared)

Post 2000

- Forward looking SAR
- UWB GPR, ...

Remark:

Where appropriate polarimetric measurements should be made

MILESTONES IN 2000 (PRELIMINARY)

- | | |
|---------------|---|
| • March | setting up of Project & SC |
| • August | creation of mine fields (soils + targets) |
| • September | test measurements (validation of test lane) |
| • October/Nov | 1st experimental campaign (7 sensors) |
| • December | 1st release of available data |

SESSION:
Role of the Operator

HUMAN COGNITION IN EMI DETECTION

Leslie Collins
Duke University

PROGRAMS AND PROGRESS

- MURI
 - Physics-based statistical signal processing and sensor fusion
- JUXOCO
 - Statistical signal processing algorithms (blind test - JUXOCO grid)
- JUXOCO/NVESD
 - Transition JUXOCO grid to real time processing - JUXOCO grid and APHill mine lanes
- HSTAMIDS, GSTAMIDS
 - Real time processing, presentation
- ARO LMDC
 - Presentation of information to the operator via audio

OVERVIEW

- Goal: Optimize presentation of information through human operator
 - Can improved signal processing be translated to a listener?
 - Is auditory performance affected by different signal coding schemes?
 - Can we predict how auditory performance will be affected by different signal coding schemes?
 - How do more optimal coding strategies affect listener performance in a task to discriminate mines from clutter (field-collected data)?

DOES PROCESSING MATTER?

- Listening task: discriminate a mine signal from a clutter signal. Experiment considered both single signals (A vs B) and a family of signals ($\{A\}$ vs $\{B\}$) (Fixed Vs Random)
- Several *signal analysis techniques* were considered
- Results presented as d' ($d' = 1.0 \sim \% \text{ correct} = 70$)

Detector	Fixed Parameters	Random Parameters
Optimal	1.12	0.87
Energy	0.73	0.72
Summation	0.42	0.38
Single Time Sample (at optimal time)	0.22	0.22

Conclusion: can translate signal processing "gains" to human listener (processing matters)

DOES CODING MATTER?

- Goal: evaluate difference ~~presentation~~ methodology
- Signal conditions: single and variable decay rates (as before)
- Two signal coding strategies:
 - Amplitude shift (AS) of 700 Hz sinusoid
 - Frequency shift (FS) in 700-1400 Hz range

DOES CODING MATTER?

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- Two signal coding strategies:
 - Amplitude shift (AS) of 700 Hz sinusoid
 - Frequency shift (FS) in 700-1400 Hz range

DOES CODING MATTER? (CONT.)

Case I	Sample	Sum	Energy	Optimal
AS	1.1	2.7	2.3	2.9
FS	2.1	3.4	3.6	3.7
Case II	Sample	Sum	Energy	Optimal
AS	1.0	1.6	1.3	2.1
FS	2.5	2.8	3.1	3.4
Case III	Sample	Sum	Energy	Optimal
AS	1.2	1.7	1.5	2.3
FS	2.8	3.2	2.4	2.8

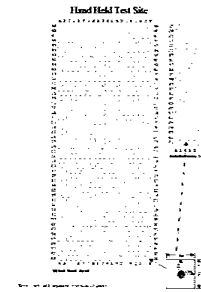
Conclusion: Coding matters

DOES CODING AND PROCESSING MATTER ON REAL DATA

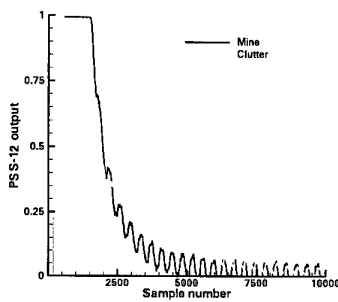
- Questions:
 - Can signal processing improvements measured for automatic algorithms be translated to a human listener
 - Does the mode of presentation affect performance
- Data: PSS-12 receive coil (amplitude versus time) measured in the calibration lanes at the JUXOCO grid
- Theoretical ROCs derived (a la earlier discussion)
- Signals presented as
 - energy
 - optimal processor output
 - frequency alone or frequency + speed (Why? HSTAMIDS)

PILOT SITE LAYOUT

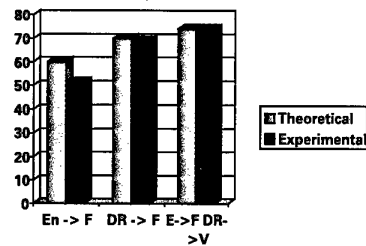
- Calibration lanes ground truth known to researchers
- Blind test grid ground truth sequestered
- 1m x 1m grids
- Mine, clutter, or “nothing” buried in center



SIGNALS



PRELIMINARY RESULTS



SUMMARY AND FUTURE PLANS

- Performance improvements associated with advanced signal processing techniques can be translated into performance gains in a listening experiment
- Utilizing cross modality coding allows presentation of “it’s metal” and “mine/no-mine” information to improve performance
- Future Work
 - Test algorithms on blind grid for independent verification
 - Provide simulated spatial information
 - Utilize model to predict performance of alternative (more advanced) signal coding techniques.
 - Test alternative sensors (MineLab)

EXPERT ANALYSIS AND TRAINING

James Staszewky
Carnegie Mellon University

ACKNOWLEDGEMENTS

- U.S. Army Research Office Grant DAAG55-98-1-0417
- PM - Mines, Countermine, and Demolition
- TSM
- TECO
- 1st BDE
- DOTD
- PM-Soldier

OVERVIEW

Goals
Approach

Scientific foundation: Identification and Analysis of Expert Skill
Expert Performance and Process Model

3 Studies Testing Prototype Training Program
Goals, Methods, Results
General Discussion
Conclusions

GOALS

Use principles, theory, and methods of Cognitive Science to understand how the most proficient operators of handheld equipment detect landmines

Apply results to train novice operators more effectively

SCIENTIFIC FOUNDATION: EXPERT PERFORMANCE AND MODEL

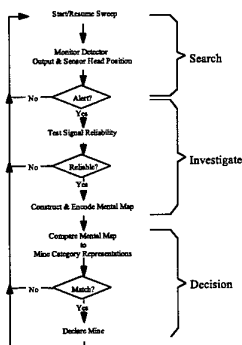
Performance testing identified 2 expert PSS-12 operators with PDs of 0.90+

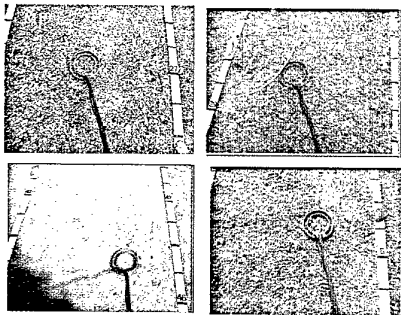
Analysis of their behavior and thinking produced an information-processing model explaining how they effectively detected landmines using the PSS-12

J. J. Staszewski, "Information processing analysis of human landmine detection skill," In *Detection and Remediation Technologies for Mines and Minelike Targets IV*, T. Broach, A.C. Dubey, R.E. Dugan, and J. Harvey, (Eds.), Proceedings of the SPIE Conference, Vol. 3710, pp. 766-777, 1999.

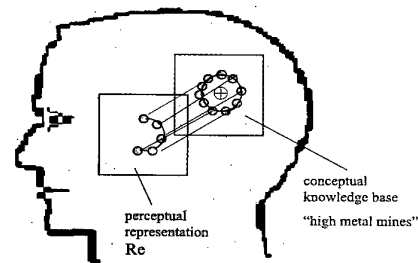
EXPERTS' UNCONVENTIONAL TECHNIQUES & STRATEGIES

Calibration SOPs: Set sensitivity using mine targets
Sensitivity Checks: Regularly check for sensitivity drift
Sweep Technique: Sensor head in contact with ground
Investigation Strategy: Construct a spatial signature or "footprint"
Decision Strategy: Interpret footprint size and shape
Airborne Technique: Localize centers of mines with big footprints





INVESTIGATION PRODUCTS & DECISION PROCESS



GOALS AND SCOPE OF PROTOTYPE TRAINING PROGRAM

Goals: Design and test training intended to improve detection capabilities of PSS-12 operators

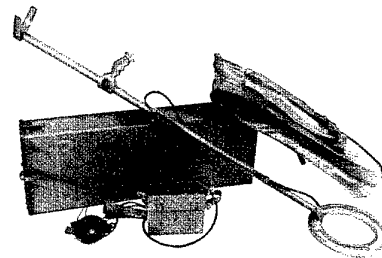
Test validity of theoretical model of expertise

Scope: U.S. Army Combat Engineers

Subsurface, pressure-triggered land mines, esp. low-metal

Hand-held detection equipment, currently fielded

Standard military-issue Schiebel AN/PSS-12 metal detector



DETECTING SET METALLIC MINE PORTABLE AN/PSS-12

TEST OF PROTOTYPE TRAINING: GENERAL DESIGN

- Pretested Experimental and Control Groups using standard US Army techniques
- Trained Exp. Group (12-15 hrs hands-on experience per soldier)
- Posttested Exp. Group after training, then Control group in same conditions w/o any intervening training/practice
- Retested Exp. Group wearing Body Armor Set Individual Countermine (BASIC)
- Retested Exp. Group at Aberdeen Proving Ground (APG) on Mines

OPERATORS

22 enlisted soldiers from 169th and 35th Combat Engineer Battalions, Ft. Leonard Wood, MO

All had just completed Advanced Individual Training, which included PSS-12 detection SOPs

Age: range 19-34; median = 22

Gen Intelligence Scores: range 85-127; med = 101.5

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TRAINING PRINCIPLES

- Train expert detection strategies and techniques
- Probability of Detection prioritized; minimal attention to target/clutter discrimination (FAR) and speed (ROA)
- Maximize hands-on practice with feedback
- Hierarchical Design - start simple, advance to more complex tasks

TARGETS: MINE SIMULANTS

- Used to provide high-fidelity low metal anti-personnel and anti-tank signatures
 - Components for metallic signatures developed by PM-MCD
 - Components available and inexpensive
 - Hockey puck carriers
- AP-LM & AT-LM targets: M14, PMA3, VS2.2
- AP, AT-Ms - common tin cans simulating M15, M16

MINE SIMULANT INSERTS

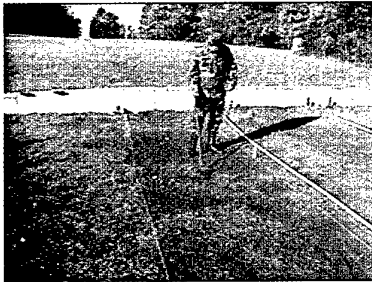
SIMULANT MINES (SIMs)

- Interchangeable inserts containing small metal parts with increasing levels of detection difficulty
- Metal parts tested based on parts typically found in mines
- Metal parts selected for inserts based on testing with five of the worlds leading mine detectors, laboratory instrument testing and detonator detection modeling
- Inserts C through K for AP mines
- Inserts G through O for AT mines
- Set of INSCOIL inserts developed to facilitate magnetic induction metal detection modeling

TARGET DISTRIBUTION @ FT. LEONARD WOOD

Mine (Simulant)	N	% total
M14	150	36%
M15	30	7%
M16	30	7%
PMA3w/S	120	28%
VS 2.2	90	22%
	420	
Type	N	%total
AT-M	30	7%
AP-M	30	7%
AT-LM	90	22%
AP-LM	270	64%
	420	

LANES FOR BLIND TESTING

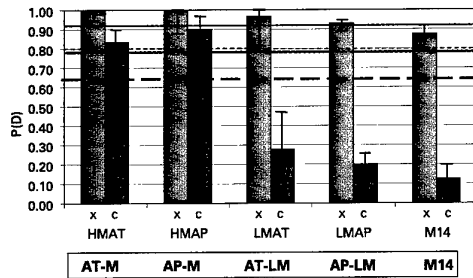


STUDY 1: OVERALL PERFORMANCE Initial Training at Ft. Leonard Wood, October '99

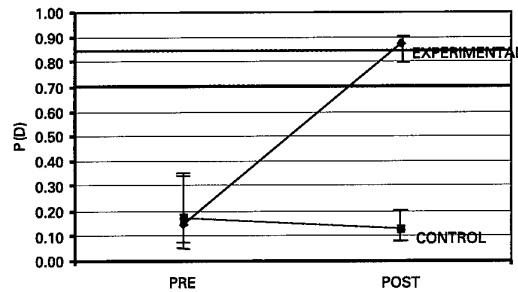
Group	PD	FAR	ROA
Experimental	0.94	0.09	80.3
Control	0.31	0.05	25.2

Note. Probability of Detection (PD) scored using 6" halo; False Alarm Rate (FAR) in FA/m²; Rate of Advance (ROA) in sec/m².

POST-TEST PERFORMANCE OF EXPERIMENTAL & CONTROL GROUPS



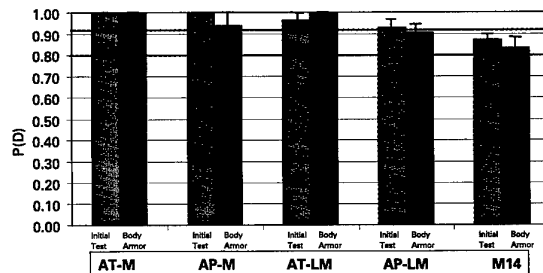
PRE-POST TREATMENT EFFECTS FOR M14 SIMULANTS



STUDY 2 GOALS

1. Test reliability of Study 1 results
2. Test generality of training effects;
Can soldiers perform effectively in body armor?

PD COMPARISON: INITIAL PERFORMANCE VS TEST IN BODY ARMOR



STUDY 3: DETECTION OF ACTUAL MINE TARGETS NOV '99

Goal: Assess generality of training effects; Would training generalize to real mines and different surfaces?

Expectation: PD would drop, especially on lanes with AT-LM and AP-LM targets.

Reason: Test site's hard-packed, crushed stone on-road lane surfaces provide no feedback on lane coverage. This increases likelihood that areas of lanes would be missed in soldiers' sweeps.

APG TEST ENVIRONMENT - ON-ROAD LANES

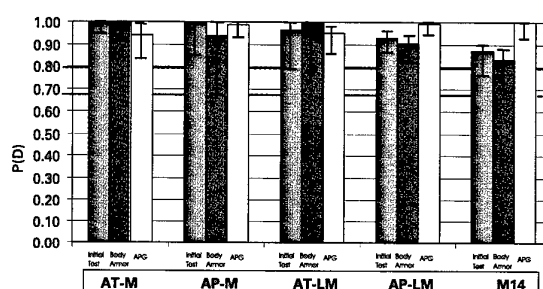
Lane	Mine	Type	Depth	N
1	TM62M	AT-M	5"	3
	VS 2.2	AT-LM	3"	3
	VS50	AP-M	flush	5
3	M15	AT-M	5"	3
	VS 1.6	AT-LM	3"	3
	M16	AP-M	flush	4
6	TM62P3	AT-LM	3"	4
	VAL 69	AP-M	flush	3
	TS50	AP-LM	1"	7
8	M19	AT-LM	3"	3
	M14	AP-LM	1"	8
	PMA3	AP-LM	1"	3
				49

EXPERIMENTAL GROUP OVERALL PERFORMANCE ACROSS TESTS

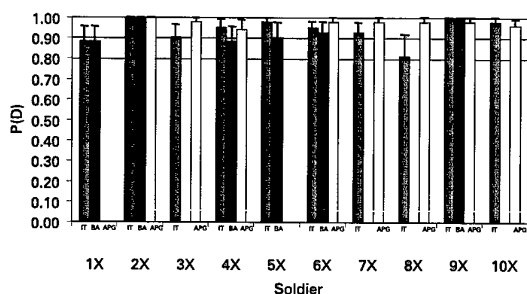
Test	PD	FAR	ROA
FLW - Initial Test	0.94	0.09	80.3
FLW -BASIC	0.93	0.10	69.4
APG	0.97	0.31	75.4

Note. Probability of Detection (PD) scored using 100; False Alarm Rate (FAR) in FAR; Rate of Advance (ROA) in sec/m

PD SUMMARY FOR 3 TESTS (FLW -INIT/ FLW-BASIC / APG)



INDIVIDUAL DIFFERENCES FOR 3 TESTS



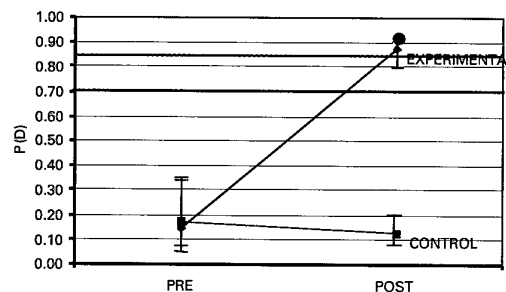
FUTURE TASKS

- Proposed Training Improvements
 - Address
 - Target/Clutter Discrimination
 - Rate of Advance
 - Investigate skill maintenance, individual differences
 - Increase realism of training & testing; extend to different op environments, e.g., low grass, high grass, hilly terrain, rocky terrain, jungle, river bed, rice paddies, clutter, diff soil types, threat mine patterns, surface mines, trip wires, booby traps, UXO, ...

CONCLUSIONS AND IMPLICATIONS

- Training problem identified: Without proper operator training, capabilities of demining technologies and personnel will be underestimated.
- Solution identified: Training based on expert skill is an effective and practical technology for training development.

PRE-POST TREATMENT EFFECTS FOR M14 SIMULANTS AND MINES



VIRTUAL MINEFIELD

Jeff McMahon
Carnegie Mellon University

OBJECTIVE AND MOTIVATION

Objective

To maximize the performance of hand-held land mine detection systems by improving the interaction between the operator and the detector.

Motivation

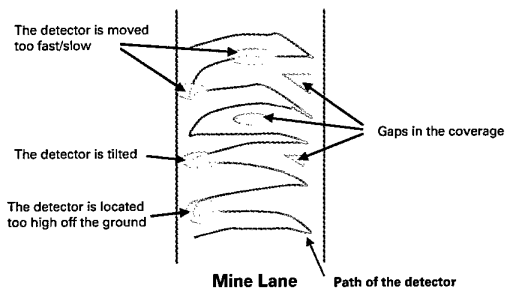
- Performance ultimately depends on the operator.
 - Gaps in coverage.
 - Improper speed.
 - Too high.
- Untapped potentials in current and future detectors can be utilized by better integration of the operator and the detector.

Currently, our effort is concentrated in addressing human-in-the-loop issues for hand-held detectors.

HUMAN-IN-THE-LOOP-ISSUES FOR HAND-HELD DETECTORS

- The output of the detector is a function of many parameters: the scanning parameters (sweep rate, sensor height and orientation), the target parameters and other environmental factors.
- The operator does not get any feedback with regard to the scanning motion (in term of sweep rate, orientation and height)
- The operator does not get any feedback on whether an area has been scanned completely (coverage problem)
- It is hard to analyze the performance of the detector, since we do Not know when the detector fails, and when the operator misuses the detector.
- No 2-D spatial representation of the detector output and no log of previous output

PROBLEMS DURING SWEEPING



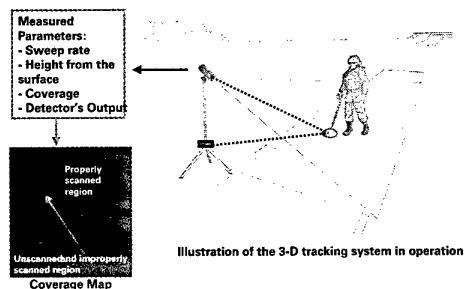
3-D POSITION TRACKER

A 3-D positioning feedback system can be used to measure the position of the detector over time, which can be used for:

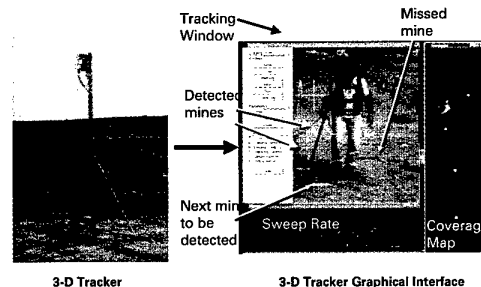
- A training aid for the operator
- An operator aid to make sure that the operator uses the detector correctly and within its optimal operating range
- An analysis tool to determine how much of the error can be attributed to incorrect sweeping technique and coverage problem
- An enabling technology to create a 2-D display for enhanced man-machine interface

The measured sweep rate, height and position can also be used to adjust the parameters of the signal processing algorithm, to compensate for the variances in the operator scanning motion

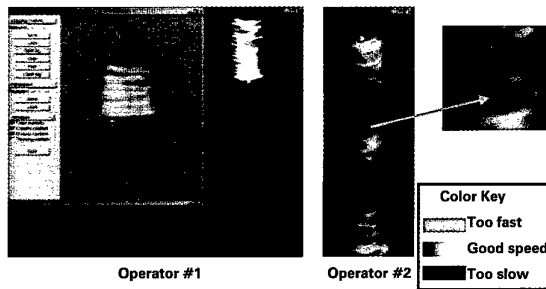
3-D TRACKER FOR REAL-TIME FEEDBACK



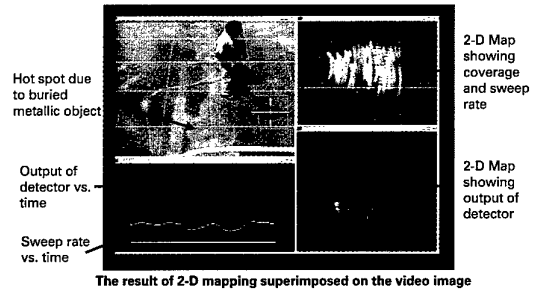
3-D TRACKER



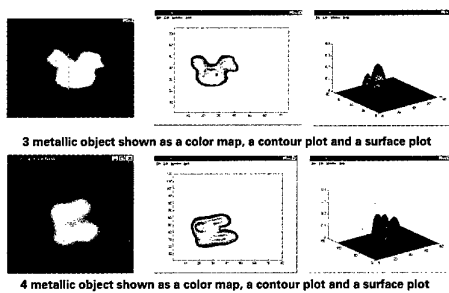
COVERAGE OVERLAY



LOGGING DETECTOR'S OUTPUT AND POSITION



2-D MAPPING EXAMPLES



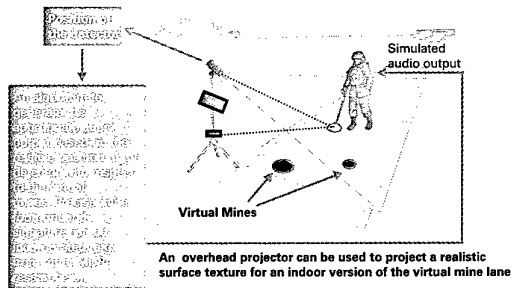
VIRTUAL MINE LANE

- Operator should be trained on a wide variety of landmines under different soil conditions.
- Very expensive to build such a mine lane.
- Hard to modify the layout and composition of the mines.

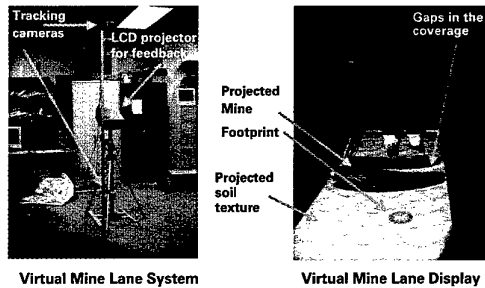
Virtual Mine Lane advantages

- Training anywhere, anytime.
- Can be used indoor or outdoor, on any surface, even a metallic surface.
- Easy to modify mine layout and types.
- Immediate feedback for operator.
- Detector models can be loaded to simulate different detectors.
- Can be used to research optimal audio output by implementing different audio signals.

VIRTUAL MINE LANE



VIRTUAL MINE LANE



SESSION:
Supplementary Presentations

MINE DETECTION TEST FACILITIES AT TNO

Henk Lensen
TNO, NL

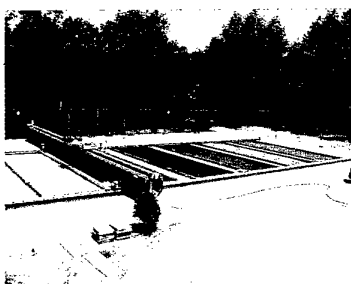
OVERVIEW

- Test facilities
 - ✓ test lanes
 - ✓ detection sensors
 - ✓ miscellaneous
- TNO policy and ambition

TEST LANES (1)

- 6 Types of soil
 - ✓ natural structure and texture
 - ✓ water level controlled
- All metal cleared test platform
 - ✓ high accuracy in position and speed
 - ✓ no metal components
- Test mines
 - ✓ checked for correct parameters
- Test and evaluation procedures
- Data collection

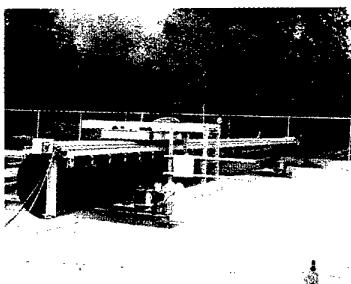
TEST LANES (2)



TEST LANES (3)

- Outdoor facility in Dutch dunes
- 6 parallel lanes with different soils
 - ✓ 5 bare soils (sand, clay, peat, ferro-magnetic, forest)
 - ✓ 1 sandy soil with vegetation cover
 - ✓ dimensions (l x w x d = 10 x 3 x 1.5 m)
 - ✓ cleared from unwanted metal
 - ✓ groundwater control
- Additional measurements
 - ✓ weather station, soil temperature, soil moisture, calibration facility...

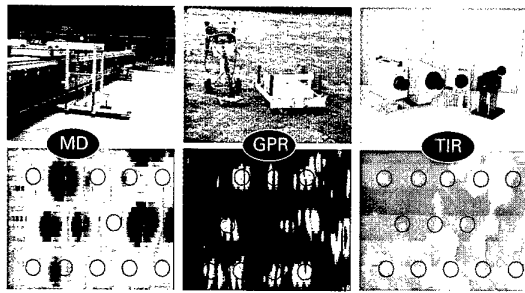
PLATFORM INCL. LASER TELEMETER (1)



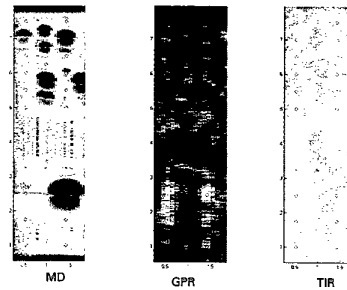
PLATFORM (2)

- Universal, non-electrically conducting
- Dimensions synthetic pipe:
 - ✓ length 17 m, diameter 0.9 m
- Payload 600 kg
- Reproducibility (< 1 cm)
- Programmable velocity (< 10 m / minute)
- Sensor specific mounts
 - ✓ height 0 - 200 cm
- Sensors TIR, MD, GPR, human ...

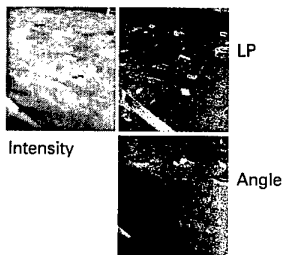
DETECTION TECHNIQUES (1)



RAW DATA



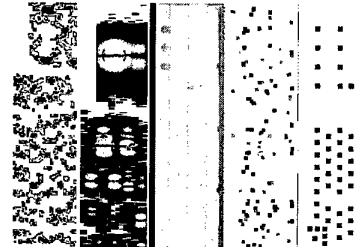
DETECTION TECHNIQUES (2)



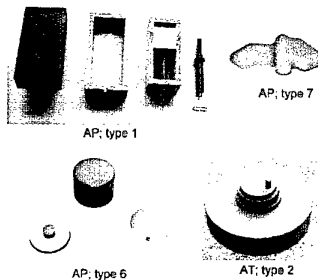
- EO sensors
 - active illumination
 - polarisation (PhD student)
- GPR sensors
 - UWB, improved processing (PhD student)
- MD sensors
 - IPPTC test of 30 COTS detectors
- Vapour detection

DETECTION TECHNIQUES (3)

- EU projects GEODE, LOTUS
 - sensors GPR, MD, TIR



TEST MINES (1)



TEST MINES (2)

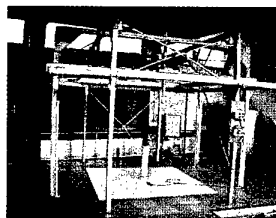
	AP mine	AP mine	AP mine
metal content	non-metal low metal metal	non-metal low metal metal	non-metal low metal metal
depth	+ 5 cm 0 cm -10 cm	+ 10 cm 0 cm -30 cm	+ 5 cm 0 cm -10 & -30 cm
objects (TNO, Army)	artificial -> real with filler	artificial -> real with filler	tin, stone, shell splinter, root ..
filler	RTV 3110	RTV 3110	no
configuration	exactly known	exactly known	exactly known

SIMULATION FACILITY MINES

Simulation and recording facility for magnetic signatures

Evaluation of:

- ✓ magnetic (mine) sensors
- ✓ mine countermeasures
- ✓ safety aspects



TNO POLICY AND AMBITION

Policy

- TNO facilities available for joint research and testing
 - ✓ sharing sensors, protocols, testmines and databases
- Independent and objective test and evaluation

Ambition

- International player in humanitarian demining
 - ✓ joint research proposals
 - ✓ certified evaluation facility
- EU network of test and evaluation
 - ✓ leading role in initiation
 - ✓ complementary facilities
 - ✓ common standards and protocols

YOME PROVING GROUNDS UXO PROBLEM IN DIVERSE ENVIRONMENT

Herbert L. VanderZyl; Soheir Ibrahim
US Army Arizona

THE PROBLEM

- There is a huge inventory of excess energetic materials due to demilitarization & stockpile reduction activities.
- Disposal of these materials must be ongoing to avoid unsafe accumulations.
- The current disposal methods, open burning & open detonation, may be prohibited in the near future.
- Base closure sites are in need of remediation.

SCOPE OF WORK

- Task 1a - (Complete)
 - Cutting cold steel
 - Procedure for cutting exterior case
- Task 1b - (Complete)
 - Laser Induced Breakdown Spectroscopy (LIBS)
 - Spectral identification

SCOPE OF WORK (CON'T)

- Task 1c - Laser cutting of inert mines
 - Demonstrate precision cutting for instrument
 - Package recovery
 - Demonstrate cutting of metal case
 - Perform safety analysis
- Task 1d - Laser cutting of live munitions
 - Performed at LANL firing site facilities
 - Laser/LIBS capability will be demonstrated
 - Base Hydrolysis, Super Critical Water
 - Oxidation of Energetic Material

LASER CUTTING OF HE CONTAINING ASSEMBLIES

- R&D Work has Established
 - Metal cases can be safely cut without significantly disturbing the HE
 - Encased explosives can be safely removed
- Metal/HE Interfaces can be observed in "Real Time"
 - Observable: Emission Spectra
 - Timescale : Microseconds

LASER USED IN STUDIES

Continued Wave (CW)

Argon Ion	514 nm	3W, 9W
CO ₂	10600 nm	300W

Pulsed

Nd: YAG	1060 nm	150 us	2 Hz
600mJ			
XeC1 Excimer	308 nm	10 ns	0.66 Hz
250mJ			
Alexandrite	760 nm	75 us	5 Hz
340mJ			
Q-Switched		150 ns	5 Hz
300mJ			

MATERIALS

Explosives

PBX 9501
PBX 9502
PBX 9407
PBX 9404
PETN

Metals

Steel
Copper
Aluminum
DU
U/Nb alloy

DoD

Composition B
CYCLOTOL
OCTOL
TNT
PETN

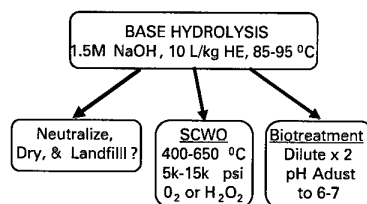
Organics

Polyimides
Polyurethane
Polycarbonate
Rubber
Phenolic
Polysulfone
Polyethylene

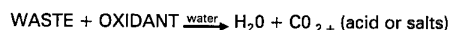
DISPOSAL TECHNOLOGIES

- Engineered System
 - Base Hydrolysis
 - Supercritical Water Oxidation
 - Bioremediation

DISPOSAL OF BASE HYDROLYSIS PRODUCTS



OXIDATION OF ORGANIC MATERIALS IN SUPERCRITICAL WATER IS A SELF-SUSTAINING LOW-TEMPERATURE CHEMICAL REACTION



- Temperature: 500-700 °C (900-1200 °F)
- Pressure: 24-35 Mpa (3500-5000 psi)
- Density: 0.1-0.3g/cm³
- Organics, Oxygen, and Water are miscible
- Transport Properties (Diffusivity, Viscosity) are Gas-Like

CONVERSION TO NON EN-MAT BASE HYDROLYSIS

- Heat EN-MAT to 60-100° in Basic Aqueous Media
- Time required varied with EN-MAT
- Sodium Hydroxide Solution (1-2 molar)

PRODUCTS FROM BASE HYDROLYSIS

- Vary with EN-MAT hydrolysed
- Non energetic in nature
- Innocuous gases liberated
- EN-MAT studied to date indicate products are salts, short chain C-C, and C-N
- Water soluble

PRODUCTS FROM BASE HYDROLYSIS

- Many Energetic Materials are decomposed by Base to give salts and short-chain organics
- Products obtained depend on the composition of the Energetic Materials
- The following compounds have been identified from Energetic Material Hydrolysis:

Gases: Ammonia, Nitrous Oxide, Nitrogen

Sodium Salts: Nitrite, Nitrate, Formate, Acetate, Carbonate, Cyanate

Organics: Dihydroxyacetone, Urea, Methanol

FUTURE WORK

- Laser cutting of live munitions
- Laser Induced Breakdown Spectroscopy (LIBS) investigation will continue
- Raman Spectroscopy has been demonstrated for species identification - will be investigated further
- Implementation of Deployable Laser-Cutting System

IMPLEMENTATION OF DEPLOYABLE LASER-CUTTING SYSTEM

Field Implementation for UXO

- Process identification and development
- Laser system specification
- Laser system development
- Development of Mobile Robotic Platform
- Development of diagnostic package
- Overall system integration
- System testing, validation and training
- Operations oversight

LASER-CUTTING OF LIVE MUNITIONS

- Instrumentation package removal from live FASCAM antitank mines
- Initiation mechanism removal for M3 SLAMs
- 81 mm mortars
- 155 mm projectiles
- Removal of initiation device from M42 grenades (live item will be done at EMRTC)

IMPLEMENTATION OF DEPLOYABLE LASER-CUTTING SYSTEM

Fixed Site Implementation for T&E

- Process identification and development
- Laser system specification
- Robotic and remote materials handling equipment
- Overall system integration
- System testing, validation and training
- Operations Oversight

PANAMA'S INTERNATIONAL CONGRESS

Gregorio Urriola Candanedo
UTP, Panama

ABSTRACT

Around the beginning of the past century, the Republic of Panama, gave to the United States of America, part of its territory for construction, operation, maintenance and defense of the Panama Canal. As a result of that contractual relation, the United States of America used a percentage of the riverside canal area for testing arms and for military exercises: As a result, this is highly contaminated by failure projectiles and remaining noxious agents that hinder the immediate utilization of those territories for civil and economical uses. The Torrijos-Carter Treaties signed in 1977, handed over to Panama the control on these areas last year. Therefore the main concern of the Republic of Panama and its public institutions and organisms, especially, those with academic and research responsibilities like the Technological University of Panama is to undertake actions conducive to develop such technology. Certainly, the first step is to know the **state of the art** of those technologies and promote the development of those that best adapt to hard conditions of the humid tropic, an environment that complicates and hinders enormously the tasks of detection and cleaning up with the equipment and instruments currently available. Besides, the desire of using appropriately reverted areas does not only involve the **demining** of those areas but previous and meticulous layout of uses of the land, which involve collaboration of many specialists.

Facing this reality we are convinced that our ongoing misfortunes can only be solved through actions of scientific development and technological transfer. Together with political will of cooperation and moral responsibility for the natural and human environment. The Republic of Panama should undertake actions of research and academic modernization. The UTP and the City of Knowledge could and should work to establish, an **International Center of Research on Technologies of Detection, Removal, Clean up and Remediation of UXOs** in Panama, in the heart of an **International Center of Studies on Materials in the Conditions of the Humid Tropic**. Such Center of Excellence will allow us to make use of the rich data of years of testing and studies gathered by the United States Army and other institutions of the American Government during their long stay in Panama. I just want to emphasize the convenience and possibility of using Panama like a center of experimentation and study of technologies in conditions of the tropic. Because of the UXOS contamination that I previously described, technology of detection and clean up of such UXOS are of interest not only for Panama but for extensive areas affected worldwide, starting in Central America and reaching to remote places in Asia as Cambodia, Laos and Vietnam, to mention only some well-known places.

To give start a long term program, the UTP, together on with other interested entities, is planning a World Conference on this topic to be held in my country and for which I would like to request the greatest support of the audience. With such objectives I request to explore the interest of your organizations and governments to define the nature and final scope of this initiative, together.

BACKGROUND. THE PROBLEM, ITS ORIGIN AND DIMENSION

Around the beginning of the past century, the Republic of Panama, gave to the United States of America, part of its territory for construction, operation, maintenance and defense of the Panama Canal

As a result of that contractual relation, the United States of America used a considerable percentage of the riverside canal area for testing arms and for military exercises: As a result, this is highly contaminated by failure projectiles and remaining noxious agents that hinder the immediate utilization of those territories for

civil and economical uses. The Torrijos-Carter Treaties signed in 1977, handed over to Panama the control on these areas last year. These treaties state that the United States should have cleaned up this territory as much as available technology could permit. Wide midland areas of my country remain profusely contaminated and they will be so as long as we don't use technology that allows us to detect, clean up and remedy those areas. Somethig needs to be done so that those areas can be used for civil, economical and commercial purposes. Therefore the main concern of the Republic of Panama and its public institutions and organisms, especially, those with academic and research responsibilities like the Technological University of Panama is to undertake actions conducive to develop such technology. Certainly, the first step is to know the **state of the art** of those technologies and promote the development of those that best adapt to hard conditions of the humid tropic, an environment that complicates and hinders enormously the tasks of detection and cleaning up with the equipment and instruments currently available. Besides, the desire of using appropriately reverted areas does not only involve the **demining** of those areas but previous and meticulous layout of uses of the land, which involve collaboration of many specialists such as urban planners, economists, sociologists and mass media experts, all whom will help present settlers and potential ones to make good use of these areas.

The affected area is located, in the middle of Panama. There even some areas very close to main urban midland of Panama which is Panama City, an area which shelters the 60% of the country's population

This area, called today Interoceanic **Region of Panama**, reaches 374 (thirty-seven thousand hectares, from which 12% are regularly covered by water (Gatún, Alajuela and Miraflores lakes). In this region 139,979 Has., are the Hidrographic Basin of the Canal and 234 (two hundred thirty-four thousand hectares remaining are what Panama designates as the **Canal Area**, which includes the surface of the previously named the **Panama Canal Zone**. From that zone, 34 thousand hectares were areas for military use and 21 thousand hectares of those, used for military training. Those polygons and areas have been affected through decades by military practices that deposited remains of explosives, failure projectiles, **defoliants** and diverse nature toxic substances. It is estimated that 1.5% of the total surface of the Canal area has serious limitations of use because of contamination by UXOS, according to the Master Plan for Land Uses of the Interoceanic Region. This was a planification instrument that my country request to a consultant company for putting in order the use of the territory that has been harded over to us.

In the area that I have mentioned before the natural richness, biological, of species of plants and animals, is really exceptional and represents an essential part of the ecological patrimony of Panama and Americas. The rich vegetation and the extended habitat of animal species on that contaminated areas complicate the clean up and remediation of those territories. In fact only a multi-disciplinary and long-term approach can help us face the enormous challenge.

On the other hand, the implicated costs are enormous. Several rough calculations derived from experiences in other contaminated areas of the world, indicate an order of magnitude of 150 millions of US dollars for cleaning up a place of 3200 hectares. Obviously this amount will be superior with the existent technology in areas of humid tropic, of dense tropical jungle.

Facing this reality we are convinced that our ongoing misfortunes can only be solved through actions of scientific development and technological transfer. Together with political will of cooperation and moral responsibility for the natural and human environment. The Republic of Panama should undertake actions of research and academic modernitation. The UTP and the City of Knowledge could and should work to establish, an **International Center of Research on Technologies of Detection, Removal, Clean up and Remediation of UXOs** in Panama, in the heart of an **International Center of Studies on Materials in the Conditions of the Humid Tropic**. Such Center will allow us to make used of the rich data of years of testing and studies gathered by the United States Army and other institutions of the American Government during their long stay in Panama. In short, we have to "Transform swords into plows" according to the well kwon Latin belief, and, for this reason, I am sure that we will for that we find the material and ethic support of governments, organizations and companies worldwide, specially those related to Panama in forms of history, commerce and culture.

I wont insist about the importance of the scientific research in regard to the materials resistance and equipment in the conditions of the tropic, aspect of primary interest from the technological and economical standpoint for many companies and organizations including textile industry and those of electronic components and telecommunications. I just want to emphasize the convenience and possibility of using Panama like a center of experimentation and study of technologies in conditions of the tropic. Because of the

UXOS contamination that I previously described, technology of detection and clean up of such UXOS are of interest not only for Panama but for extensive areas affected worldwide, starting in Central America and reaching to remote places in Asia as Cambodia, Laos and Vietnam, to mention only some well-known places.

To give start a long term program, the UTP, together on with other interested entities, is planning a World Conference on this topic to be held in my country and for which I would like to request the greatest support of the audience. With such objectives I request to explore the interest of your organizations and governments to define the nature and final scope of this initiative, together. Only like a draft I would suggest the following points to define:

2. Objective
3. Expected results
4. Organizers
5. Participants
6. Modalities
7. Place and probable date:
8. Sponsors
9. Preliminary budget.

This conference in Panama aims at contributing in solving the acute human problem of mine and UXOs pollution by create a sapace of knowledge and explain the state of the art of main and most promisory technologies for the detection, clean up and remediation of contaminated areas by mines and Uxos in humid tropic conditions and propitiate an international development of this topic.

I will thank you complete the questionnaire that I am submitting to you and contact me after the session or through electronic mail to continue improve this great idea which will be for benefit of all of us... An idea that is according to the meaning of the motto of the coat of arms of my country: **PRO MUNDI BENEFICIO.**

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